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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

XIX - A DOUBLE FLAP WITH AN OVERHANG AND

AN INTERNAL AERODYNAMIC BALANCE

By Robert B. Liddell

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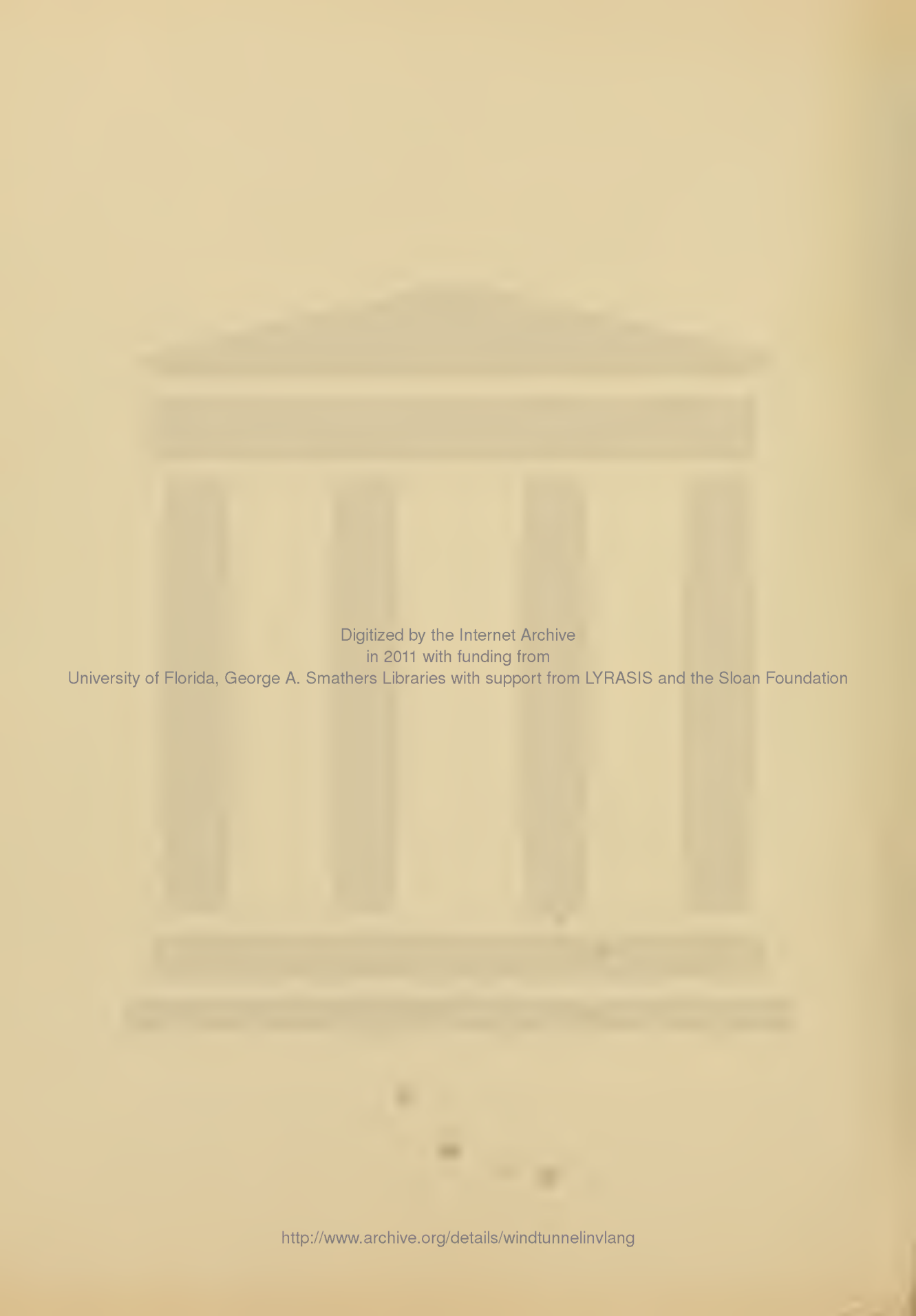

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ADVANCE CONFIDENTIAL REPORT

WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS XIX - A DOUBLE FLAP WITH AN OVERHANG AND AN INTERNAL AERODYNAMIC BALANCE

By Robert B. Liddell

SUMMARY

Wind-tunnel tests have been made in two-dimensional flow to investigate the aerodynamic characteristics of a double flap with an internal and an overhang balance. Three sizes of each type of balance were tested with three relative rates of deflection of the two flaps. An NACA 66-009 airfoil having a 0.30-airfoil-chord straight-contour forward flap and a 0.20-airfoil-chord straight-contour rearward flap was used.

The test results indicated that a balanced double flap produced the same lift as a single plain flap of the same chord and also produced highly balanced hinge moments. High lifts and low hinge moments were obtained with a double-flap arrangement if either an overhang or an internal balance having a chord 50 percent of the flap chord was incorporated on the forward flap. The overhang-balance flap showed a lower value of the hinge-moment gradient due to flap deflection than the internally balanced flap.

INTRODUCTION

Previous work (reference 1) has shown that greater lifts with lighter control forces could be obtained by the use of plain-flap small-chord control surfaces deflected to a large angle than by large-chord control surfaces with a smaller deflection range. The results of reference 1 also showed that two small-chord flaps deflected simultaneously in the same direction would be a

combination that would give even better lift and hinge-moment characteristics. Some method of incorporating aerodynamic balance must be found, however, since the hinge-moment forces of the plain flaps are much too large for these flaps to be used on high-speed airplanes.

A double flap with various amounts of either overhang or internal balance and with different rates of deflection of the two flaps has been tested to find out whether the hinge moments could be reduced and the lift characteristics of a plain flap retained. A double-flap arrangement having somewhat larger chords than those used in reference 1 was selected in order to obtain greater lift, especially at large angles of attack with flap deflections of opposite sign.

SYMBOLS

The coefficients and the symbols used in this paper are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_{d_o} airfoil section profile-drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient $\left(m/qc^2\right)$

c_{h_1} section hinge-moment coefficient about forward-flap pivot point P_1, shown in figure 1 $\left(h_1/qc_1^2\right)$

c_{h_2} section hinge-moment coefficient about rearward-flap pivot point P_2, shown in figure 1 $\left(c_{h_1}\frac{\partial\delta_1}{\partial\delta_T}\right)$

c_{h_s} control-stick (or pedal) hinge-moment coefficient $\left(h_s/qc_1^2\right)$

where

l airfoil section lift

d_o airfoil section profile drag

m airfoil section pitching moment about quarter-chord point of airfoil

h_1 forward-flap section hinge moment about F_1

h_2 control-stick (or pedal) hinge moment $\left(h_1 \frac{\delta_{1max}}{30^\circ}\right)$

c chord of basic airfoil with both flaps neutral

c_1 forward-flap chord with rearward flap neutral

c_2 rearward-flap chord

q dynamic pressure (13 lb/sq ft)

and

c_b chord of balance

α_o angle of attack for airfoil of infinite aspect ratio

δ_1 forward-flap deflection with respect to airfoil, degrees

δ_2 rearward-flap deflection with respect to forward flap, degrees

δ_T rearward-flap deflection with respect to airfoil, degrees (see fig. 3); referred to as "total flap deflection" $(\delta_1 + \delta_2)$

$$c_{l_\alpha} = \left(\frac{\partial c_l}{\partial \alpha_o}\right)_{\delta_1}$$

$$\alpha_{\delta_T} = \left(\frac{\partial \alpha_o}{\partial \delta_1}\right)_{c_l} \frac{\partial \delta_1}{\partial \delta_T}$$

$$c_{h_2{}_\alpha} = \left(\frac{\partial c_{h_1}}{\partial \alpha_o}\right)_{\delta_1} \frac{\partial \delta_1}{\partial \delta_T}$$

$$c_{h_2{}_{\delta_T}} = \left(\frac{\partial c_{h_1}}{\partial \delta_1}\right)_{\alpha_o} \left(\frac{\partial \delta_1}{\partial \delta_T}\right)^2$$

$$\left(c_{m_{c_l}}\right)_\alpha = \left(\frac{\partial c_m}{\partial c_l}\right)_{\alpha_o}$$

$$\left(c_{m_{c_l}}\right)_{\delta_1} = \left(\frac{\partial c_m}{\partial c_l}\right)_{\delta_1}$$

For comparison, all slope values are measured at an angle of attack and a flap deflection of 0° and therefore apply to only a very limited portion of the data.

APPARATUS, MODEL, AND TESTS

The tests were made in the NACA 4- by 6-foot vertical tunnel (reference 2) modified as discussed in reference 3. The 2-foot-chord by 4-foot-span model was made of laminated mahogany, except for the front flap which was steel. The airfoil conformed to the NACA 66-009 airfoil contour forward of the forward-flap hinge axis and to a straight-line contour behind this hinge axis. The model was provided with a 0.30c forward flap and a 0.20c rearward flap. Figure 1 shows the method used to connect the flaps to each other and to the airfoil. The rearward flap was connected to the forward flap by a mechanism that allowed the rearward flap to deflect one, two, or three times as fast as the forward flap; that is, $d\delta_2/d\delta_1$ equals either 1, 2, or 3. The forward flap was provided with three interchangeable blunt-nose overhang balances and three interchangeable internal balances having chords 25, 40, and 50 percent of the forward-flap chord. The arrangements tested and pertinent model dimensions are shown in figure 2.

The double-flap arrangement tested is in reality a flap with a large leading tab. The tab could have been linked to the airfoil with a single cross-link connection. The model was made with the linkage system shown in figure 1, however, and it should be noted that points P_1 and P_2 are the actual flap pivot points on the model and that the aerodynamic characteristics are the same as for a 0.30c flap with a 0.20c leading tab. The rearward-flap deflection and the rate of deflection (mechanical advantage of rearward flap over forward flap) can be obtained analytically. If x and y are as indicated in figure 1,

$$\sin \delta_2 = \frac{x}{y} \sin \delta_1 \qquad (1)$$

and

$$\frac{d\delta_2}{d\delta_1} = \frac{x \cos \delta_1}{y \cos \delta_2} \qquad (2)$$

The departure of rearward-flap deflection and of rate of rearward-flap deflection from linearity with forward-flap deflection, as calculated from equations (1) and (2), is indicated in figure 3 for each linkage arrangement tested. It may be noted that a linear rate of rearward-flap deflection, and hence a constant value of $d\delta_2/d\delta_1$, throughout the deflection range was obtained only when $\frac{d\delta_2}{d\delta_1} = 1$; that is, when $x = y$. It may also be noted that $x = 2y$ for $\frac{d\delta_2}{d\delta_1} = 2$ and that $x = 3y$ for $\frac{d\delta_2}{d\delta_1} = 3$.

The airfoil model when mounted in the tunnel completely spanned the test section. With this type of installation, two-dimensional flow is approximated and section characteristics of the model can be determined. The tests were made at a dynamic pressure of 13 pounds per square foot, which corresponds to an air velocity of about 71 miles per hour at standard sea-level conditions. The test Reynolds number was approximately 1,310,000. (Effective Reynolds number = Test

Reynolds number × Turbulence factor. The turbulence factor for the NACA 4- by 6-foot vertical tunnel is 1.93.)

With the internally balanced arrangements, the gap between the forward flap and the cover plates was 0.005c. The gap between the rearward flap and the cover plates on the forward flap varied with flap deflection. In all cases, for both internal and overhang balances, the gaps at the nose of the balance on the forward flap and the gap between the forward and rearward flaps were sealed with thin sheet rubber.

An experimentally determined tunnel correction was applied to the lift. The angle of attack and hinge moments were corrected for streamline curvature of the flap that is induced by the tunnel walls. The method used to determine these corrections is similar to the theoretical analysis of reference 4. Values of drag are subject to an undetermined tunnel correction. The data were corrected as follows:

$$c_l = \left(0.965 - 0.007 \left|c_{l_T}\right|\right) c_{l_T}$$

$$\alpha_o = \alpha_{o_T} + 0.21 \left(c_{l_T} + K c_{l_{T_f}}\right)$$

$$c_h = c_{h_T} + 0.073 c_{l_T} F$$

where c_h denotes any hinge-moment coefficient, $c_{l_{T_f}}$ is the tunnel lift coefficient produced by deflection of the flap (arbitrarily taken at $\alpha_{o_T} = -8^\circ$), the subscript T denotes a value from the tunnel, and K and F are constants that are functions of balance arrangements and are given in the following table:

c_b/c_l / $d\delta_1/d\delta_2$	K	F		
		0.25	0.40	0.50
1	-0.68	0.008	0.007	0.006
2	-.72	-----	.009	.008
3	-.76	-----	-----	.011

RESULTS

Lift and hinge-moment characteristics are presented in figures 4 to 15 for each of the arrangements of

balanced double flap tested. Pitching-moment characteristics are also presented in some of these figures for the balance arrangements having lift and hinge-moment characteristics that were considered reasonably satisfactory.

The effectiveness and hinge-moment parameters in table I are based on total flap deflection. The hinge moments, as measured about the forward-flap pivot F_1, were transferred to the rearward-flap pivot F_2. The hinge-moment and effectiveness parameters thus are comparable for the various arrangements tested, regardless of the relative rate of deflection between the forward and rearward flaps.

DISCUSSION

Lift

The slopes of the lift curves are in agreement with those measured from previous tests of the NACA 66-009 airfoil (reference 5). At large positive flap deflections for large negative angles of attack, c_{l_α} becomes very great regardless of balance type, size, or relative rates of deflection of the two flaps. This effect is characteristic of small-chord flaps. The shapes of some of the lift curves at high flap deflections are similar to those of reference 5. The overhang balance would protrude well into the air stream at high flap deflections and thus cause air-flow separation.

The lift effectiveness a_{δ_T} decreases somewhat with increase in $d\delta_2/d\delta_1$ for all types and sizes of balance tested (table I). The decrease in effectiveness may be accounted for by the fact that the forward flap has a greater effectiveness than the rearward flap and as $d\delta_2/d\delta_1$ increases the forward-flap deflection decreases for a given total deflection δ_T. The more effective flap thus moves more slowly and the less effective flap moves faster. The effectiveness of the combination should therefore decrease.

The decrease in a_{δ_T} with increase in $d\delta_2/d\delta_1$ is clearly evident in figure 16, which shows airfoil section lift coefficient against total flap deflection as obtained from figure 3. The similarity of the slopes shown in figure 16 indicates that the lift of these double-flap combinations is more nearly a function of the total flap

deflection than of either of the separate flap deflections. For comparison, the lift coefficient of the 0.20c double plain flap reported in reference 1 has been plotted in figure 16. Even though a different airfoil section was used, smaller-chord flaps produce less lift than the large-chord flap for positive flap deflections at zero and negative angles of attack - an attitude critical for a horizontal tail. The small-chord flap, however, produces even greater lifts than the large-chord flap at high positive angles of attack - an attitude usually critical for a rudder. Figure 16 indicates that the flap with an internal balance and the flap with an overhang balance have about the same lift at the same flap deflection and at $\alpha_o = 0°$, although the flap with overhang balance shows just slightly greater lift. Data for the 0.30c plain flap of reference 5 are also presented in figure 16 and the similarity of the lift characteristics and those of the 0.30c double flap should be noted.

Hinge Moment

The hinge-moment coefficients of the arrangements of balanced double flap tested showed little change with angle of attack in the region of low angle of attack (figs. 4 to 15). The curves are typical of most low-drag airfoils tested at low scale, however, in that they rapidly become increasingly nonlinear beyond $\alpha_o = \pm 6°$. A negative value for $c_{h_{2_\alpha}}$ is indicated for all of the arrangements except the $0.50c_1$ overhang balance with $\frac{d\delta_2}{d\delta_1} = 1$, for which $c_{h_{2_\alpha}}$ was about zero (table I). The flaps with a $0.40c_1$ or a $0.50c_1$ overhang balance tended to have a more positive value of $c_{h_{2_\alpha}}$ than the flaps with an internal balance of equal chord. The value of $c_{h_{2_\alpha}}$ becomes zero and sometimes positive at flap deflections other than 0° for most of the arrangements tested.

At large positive flap deflections and large negative angles of attack, the hinge-moment coefficients change rapidly from a large negative value to almost zero at large negative lifts. This rapid change in hinge-moment coefficient occurs in the same lift range and at the same large flap deflection for which the slope of the lift curve

becomes excessively steep. This rapid change of the hinge-moment coefficient might cause reversal of control-surface force but, in any case, the force required to return the control surface to neutral should be relatively small.

Of the arrangements tested, the double flap with either a $0.50c_1$ internal or a $0.50c_1$ overhang balance has values of $c_{h_{2_{\delta_T}}}$ low enough to warrant its consideration for an airplane tail control surface. The overhang balance had a lower value of $c_{h_{2_{\delta_T}}}$ than the internal balance. The value remains fairly constant up to large flap deflections for the more usable arrangements.

The balanced double flap and the linked-balance flap are shown schematically in figure 17, which indicates that a linked-balance arrangement may be considered a balanced double flap having coincident forward and rearward flaps. By using the equations (see fig. 17)

$$\delta_1 + \delta_2 = \delta_T$$

and

$$\frac{d\delta_1}{d\delta_T} = \frac{1}{1 + \frac{d\delta_2}{d\delta_1}}$$

it is thus possible to compare the linked-balance flap and balanced double flap on the basis of rate of flap deflection $d\delta_1/d\delta_T$.

The variation of the hinge-moment parameters with rate of flap deflection is shown in figure 18. Also included for comparison are the curves for a $0.30c$ flap with a $0.50c_1$ linked overhang balance (reference 5). An examination of figure 18 indicates that $c_{h_{2_\alpha}}$ varies very little with the rate of deflection whereas $c_{h_{2_{\delta_T}}}$ is affected to a much greater extent. For the particular arrangement tested, the parameters for the balanced

double flap are smaller than those for the flap with the linked overhang balance.

The stick hinge-moment coefficients for the balanced double flap with a $0.50c_1$ balance are shown in figure 19 as a function of lift coefficient at three angles of attack. The characteristics of the linked-balance flap (reference 5), a 0.35c flap having conventional overhang balance (reference 6), and a 0.20c double plain flap (reference 1) are also included in figure 19 for comparison. The control stick was assumed to be limited to a maximum deflection of 30°. The total flap deflection was approximately 30° for all of the arrangements except the double plain flap for which it was 60°. By limiting the total flap deflection as indicated, the curves are nearly equal with respect to maximum lift. The curves of figure 19 therefore take into account the mechanical advantage of the system and extrapolation to a higher lift coefficient would not be valid unless the slope is increased. The curve for the double plain flap, presented in figure 19(a), was taken directly from reference 1 for $\frac{d\delta_2}{d\delta_1} = 1$ and the hinge-moment coefficients were based on a 0.30c flap. Because this particular double plain flap had a total flap deflection of 60°, a higher lift coefficient was obtained at $\alpha_0 = 0°$ even though the flap chord was somewhat shorter.

Causing the rearward flap to move increasingly faster than the forward flap generally increased the stick hinge-moment coefficient for any particular value of lift coefficient. The reverse was true with regard to the double plain flap reported in reference 1. This apparent discrepancy might be explained in the following manner: The decrease in hinge moment with increase in the value of $d\delta_2/d\delta_1$ for the double plain flap is indicative of an increasingly better camber for the airfoil. By incorporating a balance that is attached to the forward flap, however, the forward flap would move more slowly as the rate of flap deflection $d\delta_2/d\delta_1$ increased and therefore the balance would be less effective for the same total flap deflection. The curves of figure 19(b) indicate that the linked-balance flap has higher hinge moments and lower maximum lift than the

balanced double flap with $\frac{d\delta_1}{d\delta_T} = 0.50$. From this comparison, a leading tab somewhat shorter than the flap chord causes a smaller hinge moment for a given lift than a $1.00c_1$ leading tab (linked overhang balance). This fact might be explained by the more gradual curvature of the air, the smaller peak pressures at the hinge axis, and a smaller adverse pressure gradient, with a consequential later separation of flow, for the balanced double flap than for the linked-balance flap. Unpublished results, however, indicate that, for a leading tab with a chord a little shorter than 50 percent of the flap chord, the hinge-moments increased at a more rapid rate than the lift when the tab was deflected with the elevator. The arrangement is therefore unsatisfactory. All available data indicate that some intermediate chord would be the optimum for the tab rather than a very small or a very large chord. Whether the tab chord used in the tests reported herein is the optimum is still indeterminate. There are not enough data available, however, to determine the optimum chord for a large leading tab and further tests are recommended to provide the data necessary for finding the optimum flap chords and deflection rates. The curves of a convertional overhang balance that would be well balanced at small flap deflections are shown for comparison in figure 19. The advantages of a double-flap arrangement are evident.

Flap oscillation was noted for two arrangements of balanced double flap over a portion of the range tested. All ranges in which this oscillation of the flap occurred are shown by dashed lines in the hinge-moment curves of figures 4 to 15. This oscillation was similar to that reported in reference 5.

Drag

Increment of airfoil section profile-drag coefficient caused by flap deflection against total flap deflection at $\alpha_o = 0^\circ$ is presented in figure 20 for all arrangements tested. For small total flap deflections (under 20°), the type of balance had little effect on the profile-drag coefficient for all arrangements tested. At large total flap deflections, however, the flap with an overhang balance had more drag than with an internal balance. This result seems reasonable because an overhang balance

tends to induce air-flow separation at high deflections with a consequential increase in drag. At large flap deflections, the drag decreases with an increase in $d\delta_2/d\delta_1$.

The increment of airfoil section profile-drag coefficient caused by flap deflection is shown as a function of section lift coefficient in figure 21, in which figures 16 and 20 have been combined and replotted. The relative positions of the internal-balance curves are an indication of the amount of separation occurring over the double-flap combinations. The upper surface is not broken by the protrusion of a balance that would precipitate separation, as is the case with an overhang balance. It is evident that, in the region of higher lift, the resultant camber of the airfoil when $d\delta_2/d\delta_1$ is increased tends to produce a pressure gradient over the airfoil which induces a later and less pronounced separation than when the flaps move at the same rate. Comparison of the drag plotted against lift for the short-chord double plain flap of reference 1 and the longer-chord internally balanced double flap of the present report indicates that the profile-drag coefficient for any particular lift coefficient was generally somewhat higher for the double-flap arrangement with the short chord.

Pitching Moment

The pitching-moment curves are linear for small flap deflections but change rapidly with angle of attack at large flap deflections. The rapid decrease in pitching-moment coefficient at negative angles of attack and large positive flap deflections in the same region in which values of hinge moment and lift change rapidly is characteristic of small-chord flaps. Pitching-moment parameters, measured from the data of figures 4 to 15 and from some data not shown in these figures, are given in table I. These values are an indication of the locations of the centers of lift caused by angle of attack and by flap deflection.

CONCLUSIONS

The results of tests of an NACA 66-009 airfoil with a 0.30-airfoil-chord straight-contour double flap having an overhang and an internal balance of various chords and several rates of deflection for the two flaps indicated the following conclusions:

1. The balanced double flap produced lifts about equal to a single plain flap of the same chord and at the same time produced closely balanced hinge moments.

2. High lifts and low hinge moments were obtained with a double-flap arrangement if either an overhang or an internal balance having a chord 50 percent of the flap chord was incorporated on the forward flap. The data also indicated that, for the arrangements tested, the forward and rearward flaps should deflect at about the same relative rate.

3. The relative rate of deflection of the two flaps had a large effect on the hinge moment due to flap deflection and a small effect on the hinge moment due to angle of attack.

4. The flap having an overhang balance showed a lower value of the hinge-moment gradient due to flap deflection than the internally balanced flap.

5. The rapid change in hinge-moment coefficient at large flap deflections and angles of attack of opposite sign may cause reversal of control-surface force; however, a relatively small force should be required to return the control surface to neutral.

6. A double-flap arrangement incorporating an aerodynamic balance is a very promising arrangement. Inasmuch as this double flap is merely a large leading tab, its incorporation on the tail of an airplane should not present any particularly difficult problem. There

are not enough data available, however, to determine the optimum chord for a large leading tab and further tests are necessary to find the optimum flap chords and deflection rates.

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TABLE I

INFORMATION CONCERNING ARRANGEMENTS OF BALANCED DOUBLE FLAP TESTED

c_b/c_1	$\frac{d\delta_2}{d\delta_1}$	c_{l_α}	a_{δ_T}	$c_{h_{2_\alpha}}$	$c_{h_{2_{\delta_T}}}$	$\left(c_{m_{c_l}}\right)_\alpha$	$\left(c_{m_{c_l}}\right)_{\delta_1}$	Figure
Internal balance								
0.50	1	0.099	-0.54	-0.0010	-0.0028	-0.194	0.011	4
.50	2	.096	-.50	-.0011	-.0037	-.190	.021	5
.50	3	.092	-.47	-.0010	-.0044	-.193	.017	6
.40	1	.100	-.53	-.0020	-.0053	-.184	.013	7
.40	2	.095	-.50	-.0020	-.0054	-.191	.008	8
.25	1	.100	-.53	-.0029	-.0068	-.183	.007	9
Overhang balance								
0.50	1	0.099	-0.50	0.0000	-0.0021	-0.193	0.005	10
.50	2	.098	-.48	-.0004	-.0037	-.213	.014	11
.50	3	.101	-.48	-.0006	-.0041	-.213	.006	12
.40	1	.098	-.57	-.0016	-.0054	-.190	.015	13
.40	2	.097	-.52	-.0015	-.0051	-.197	.015	14
.25	1	.103	-.52	-.0030	-.0074	-.192	.006	15

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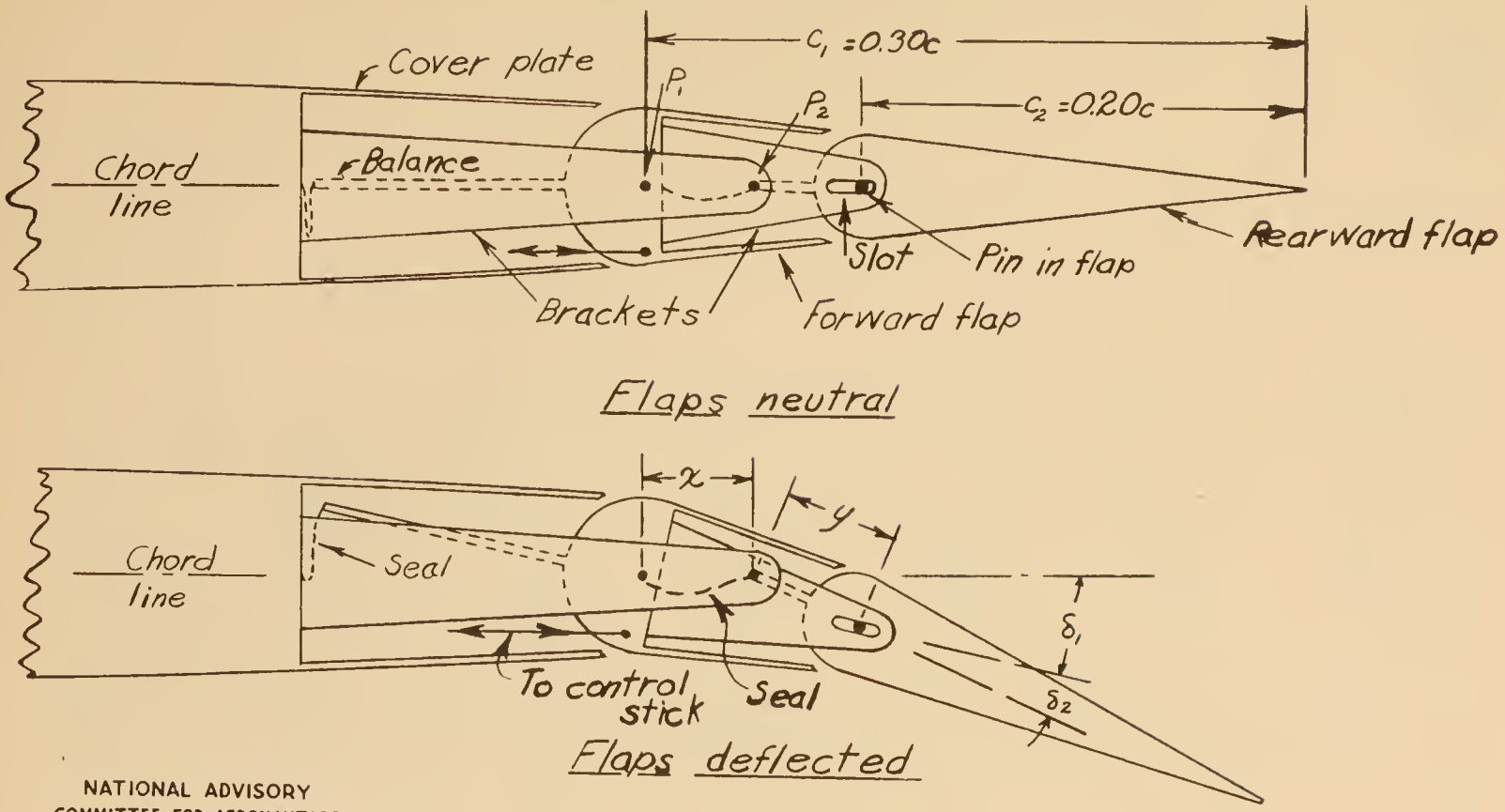
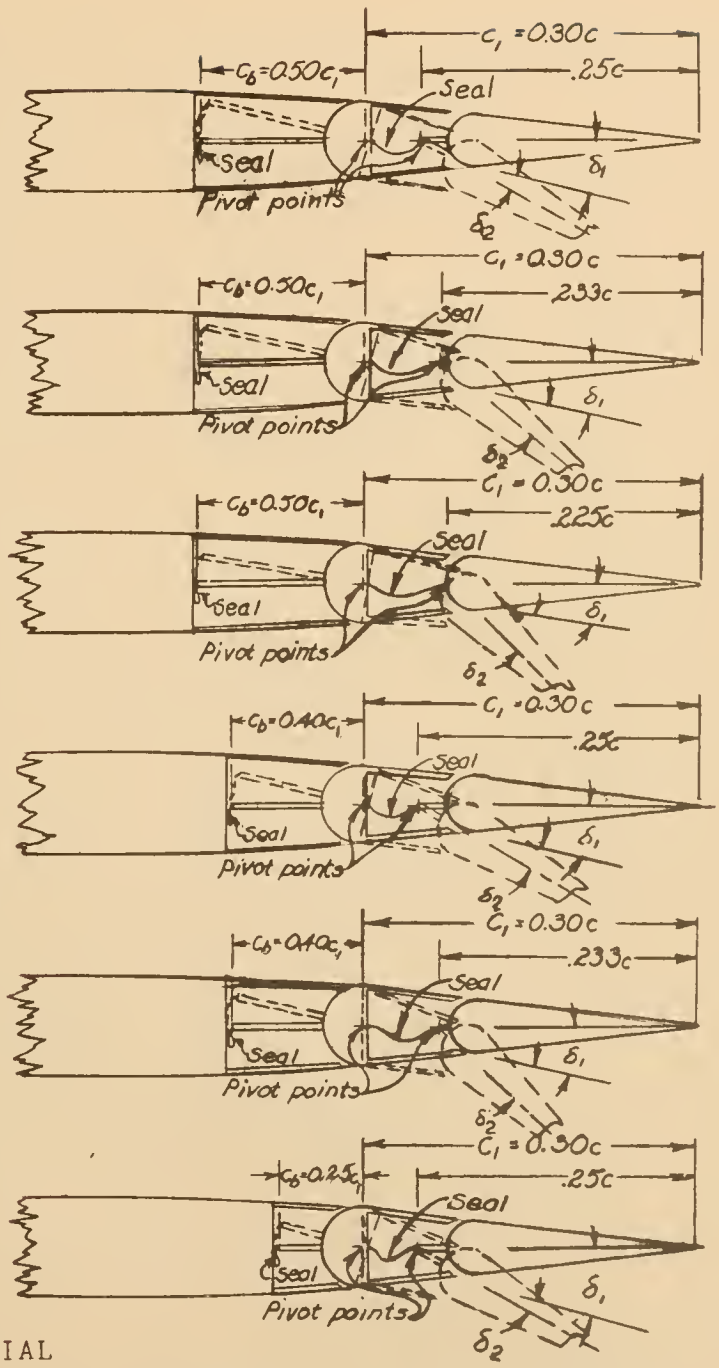


Figure 1.- Schematic diagram of linkage system used to deflect balanced double flap.

Data in figure	$\frac{d\delta_2}{d\delta_1}$
4	1
5	2
6	3
7	1
8	2
9	1



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(a) Internal balances.

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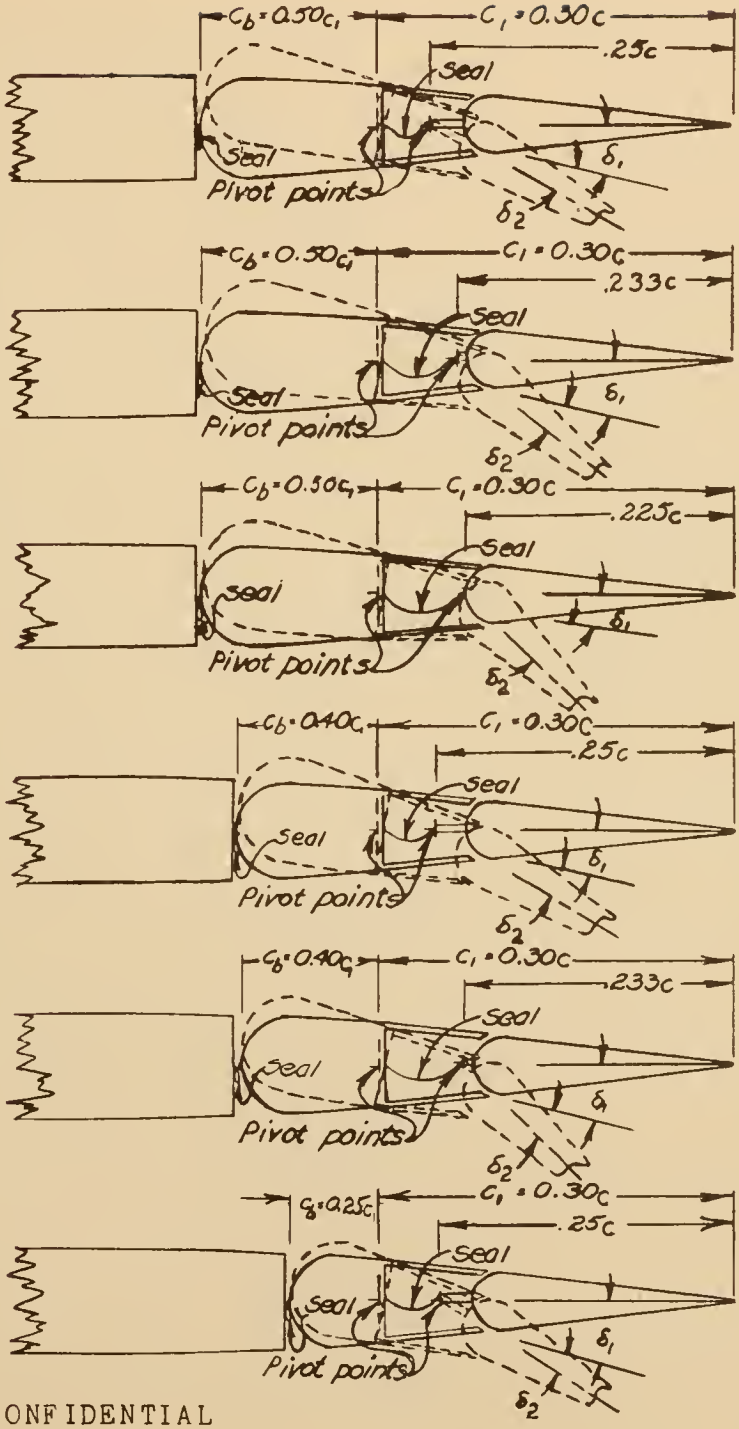
Figure 2.- Arrangements of balanced double-flap model tested. NACA 66-009 airfoil having a 0.30c double flap.

Data in figure	$\frac{d\delta_2}{d\delta_1}$
10	1
11	2
12	3
13	1
14	2
15	1



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(b) Overhang balances.

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Figure 2.- Concluded.

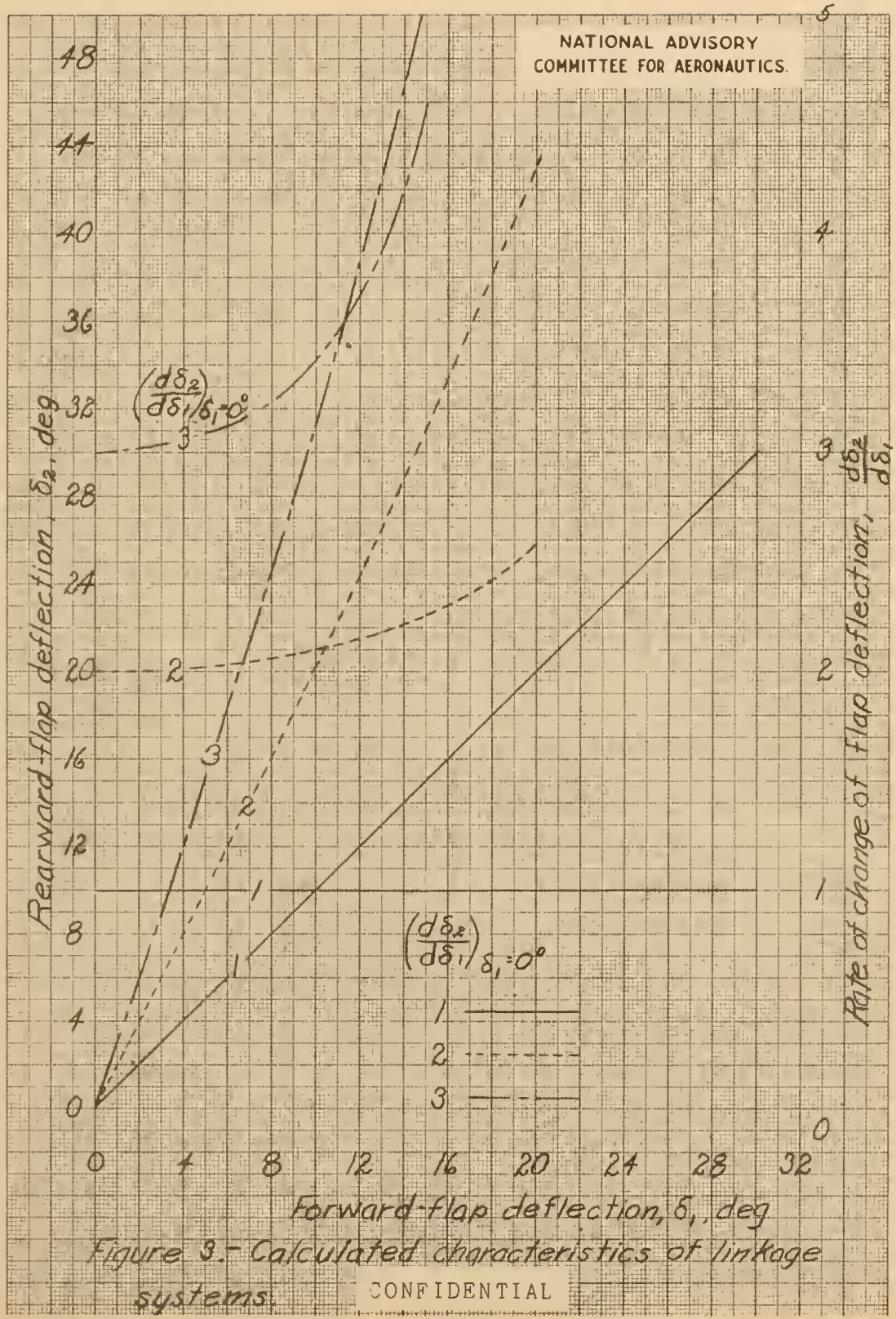


Figure 3.- Calculated characteristics of linkage systems.

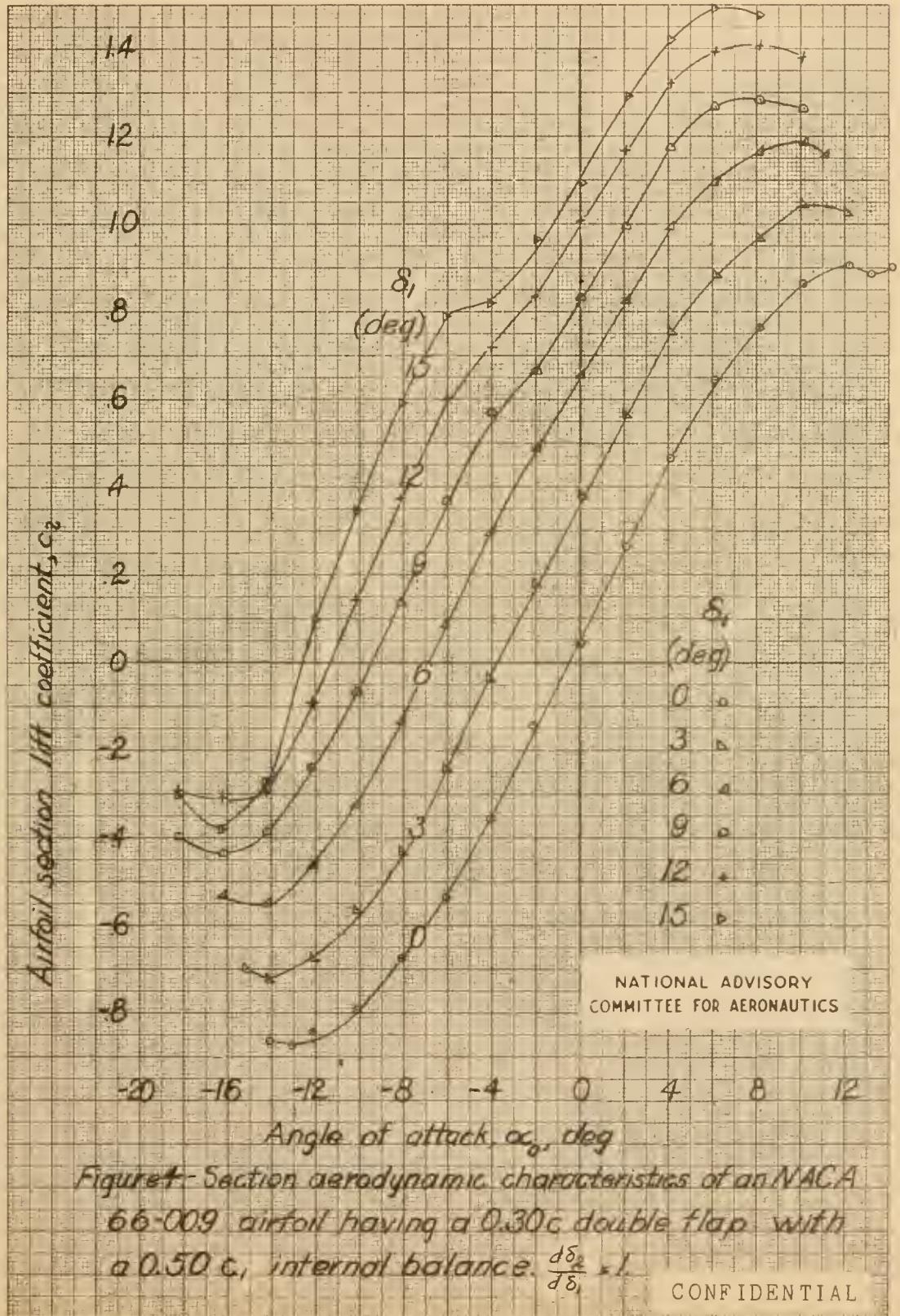


Figure 4.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.50 c, internal balance. $\frac{d\delta_2}{d\delta_1} = 1$.

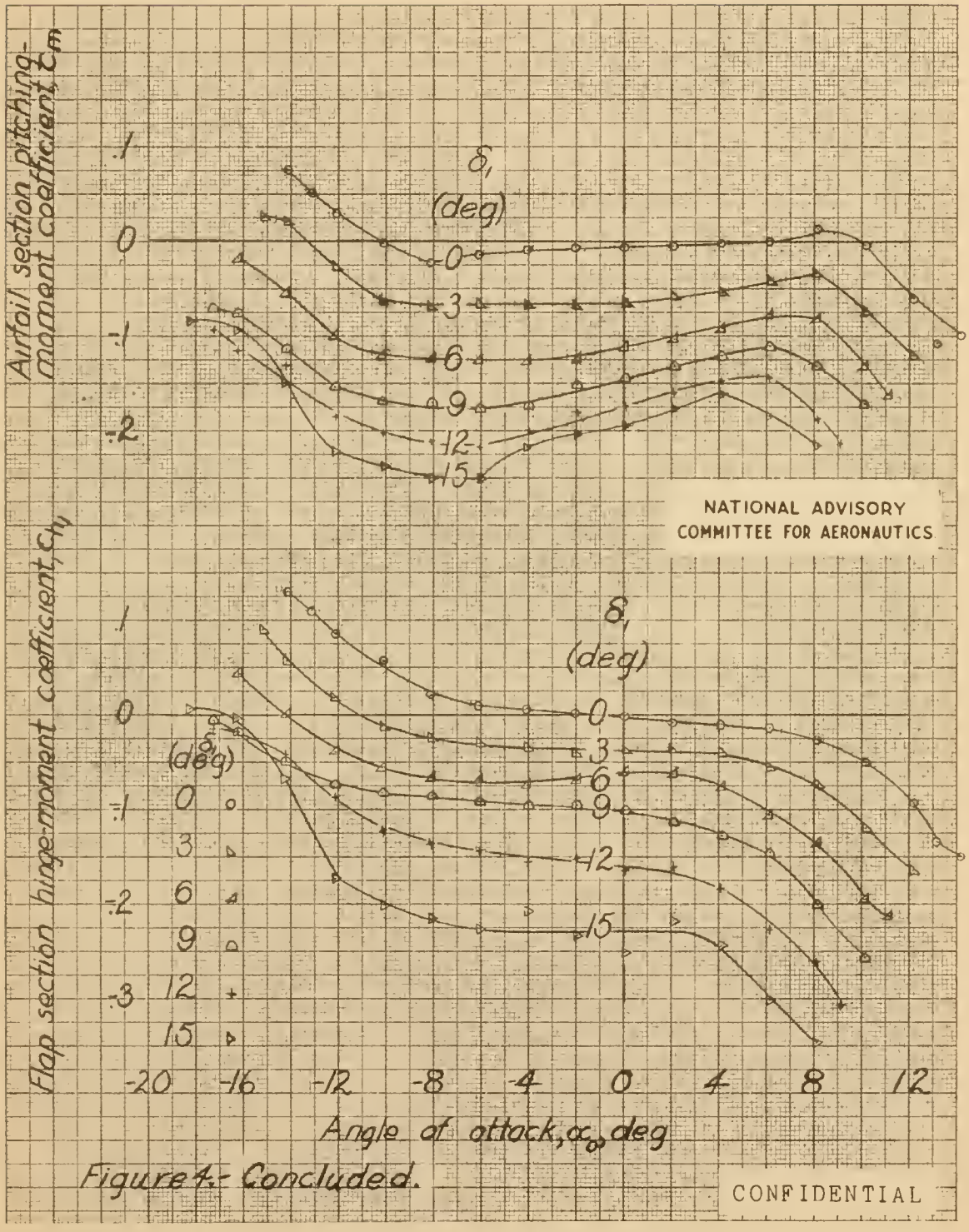


Figure 4.- Concluded.

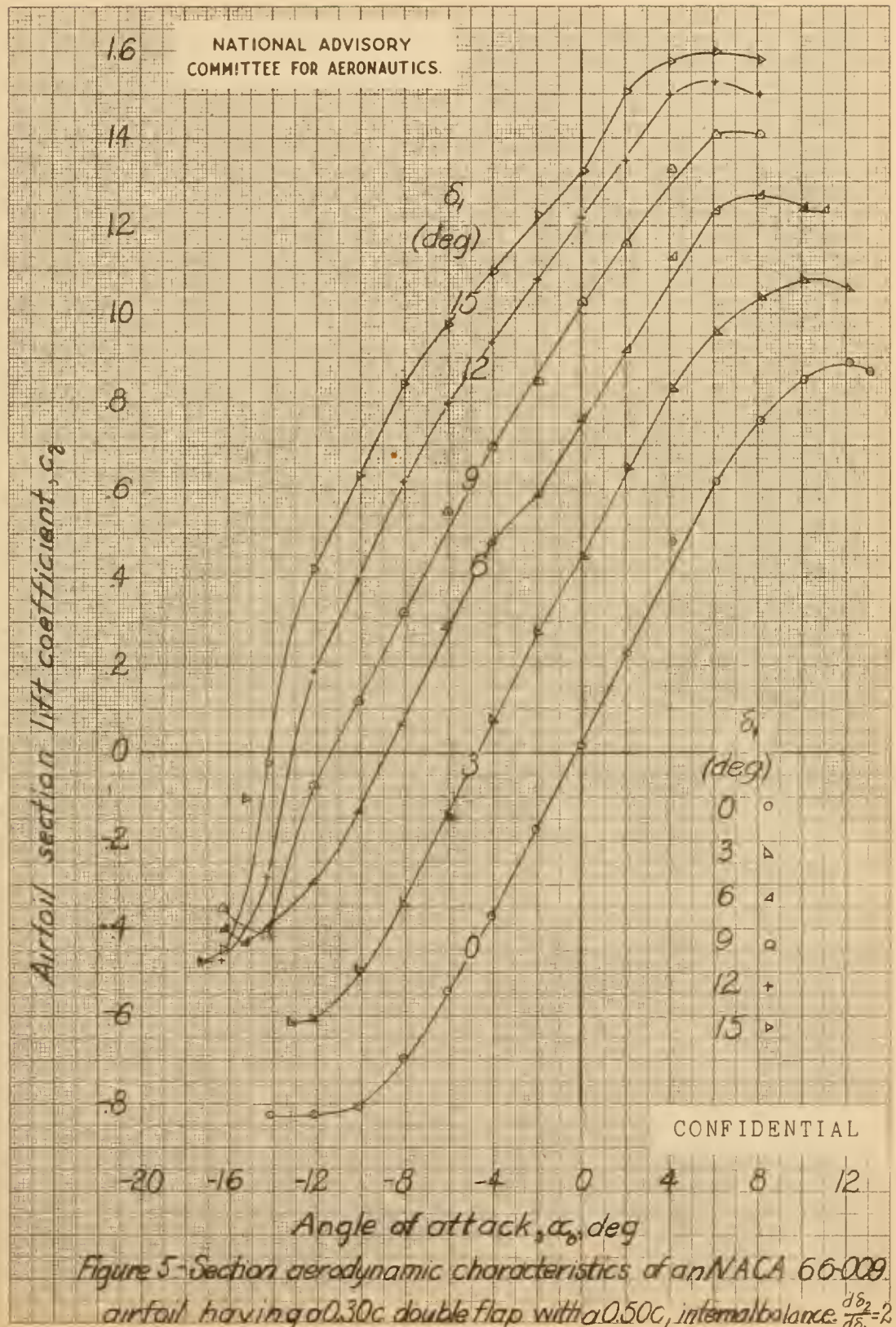
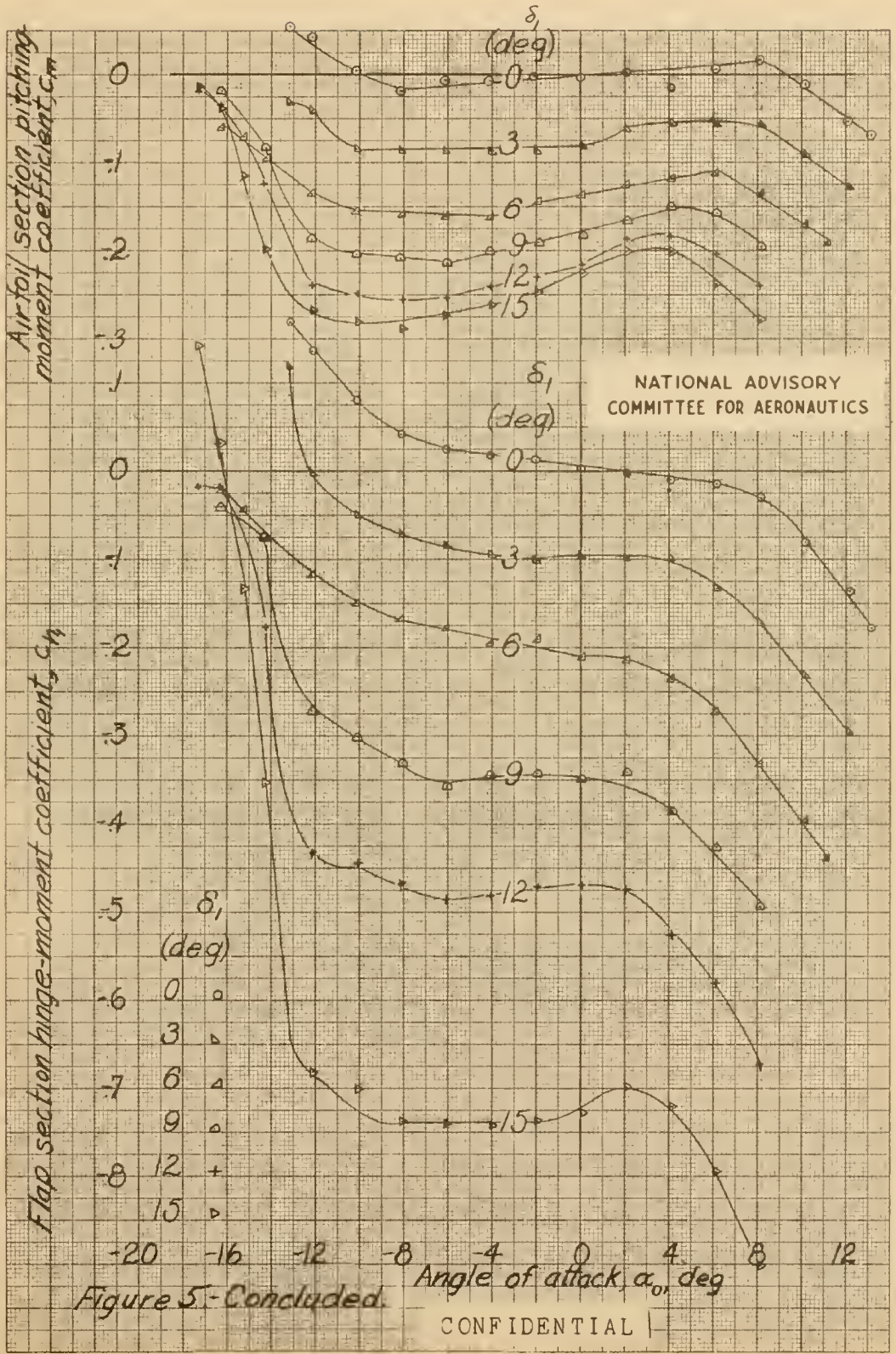


Figure 5 - Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.50c, internal balance. $\frac{d\delta_2}{d\delta_1} = 2$



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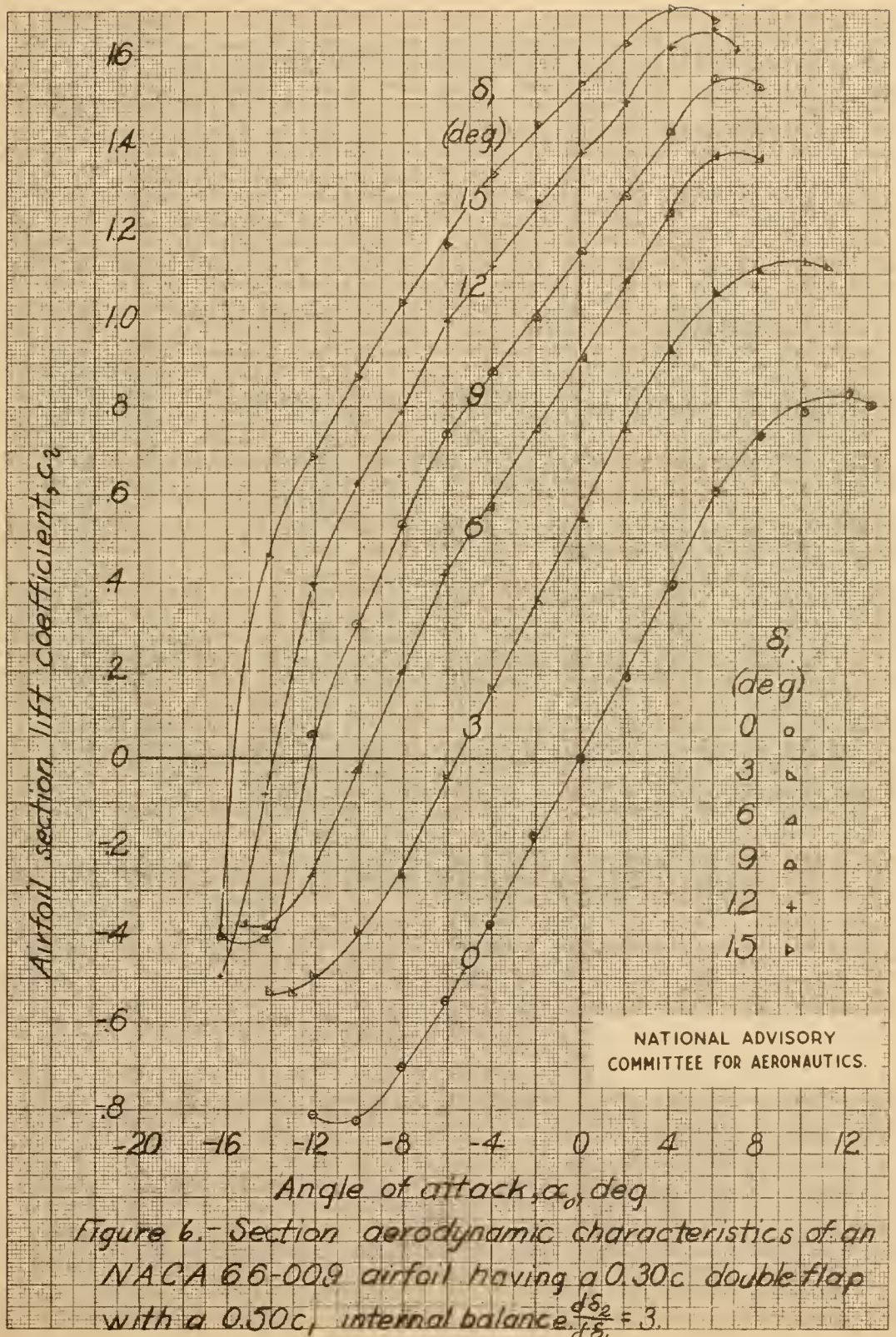
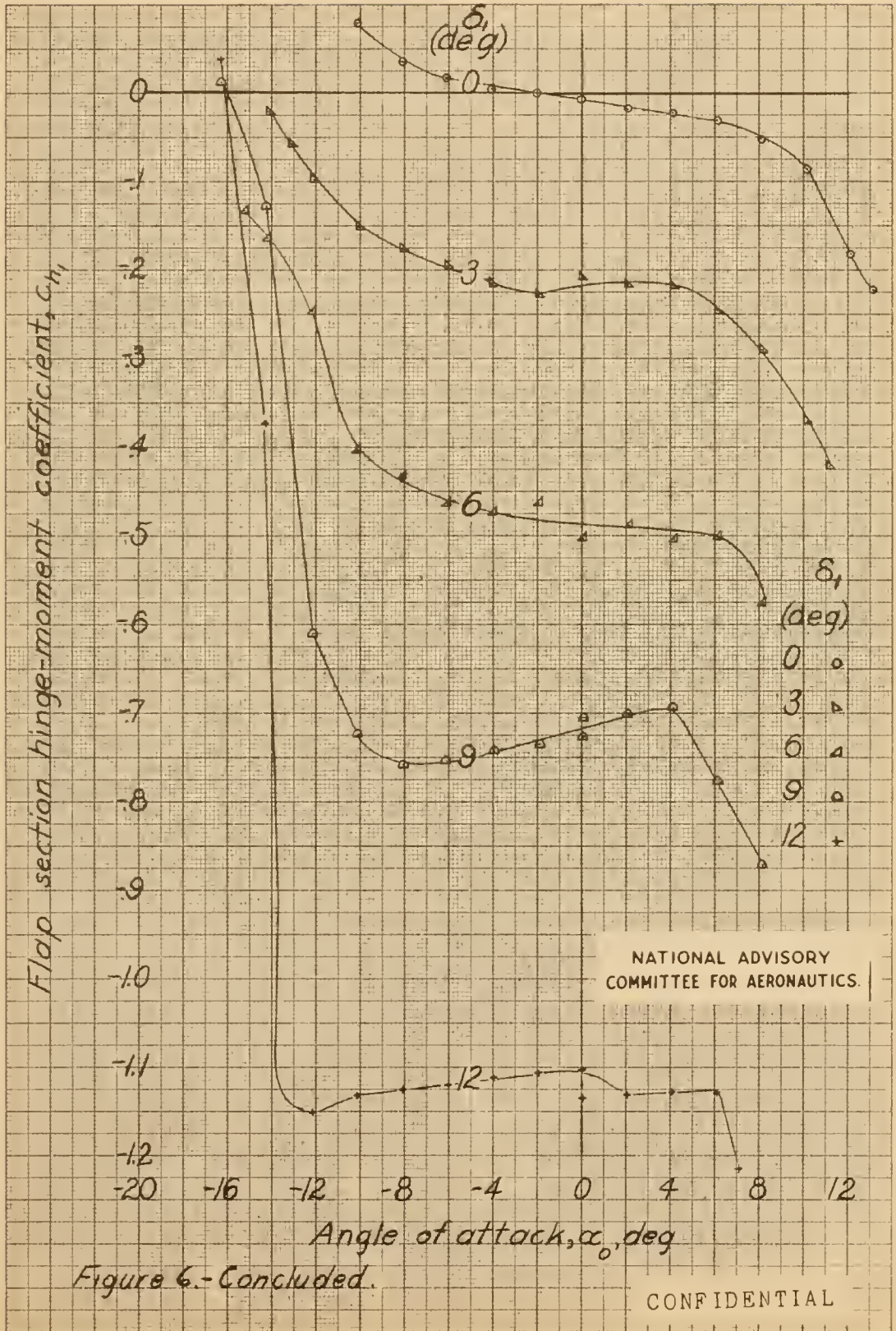


Figure 6.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.50c, internal balance, $\frac{d\delta_2}{f\delta_1} = 3$.



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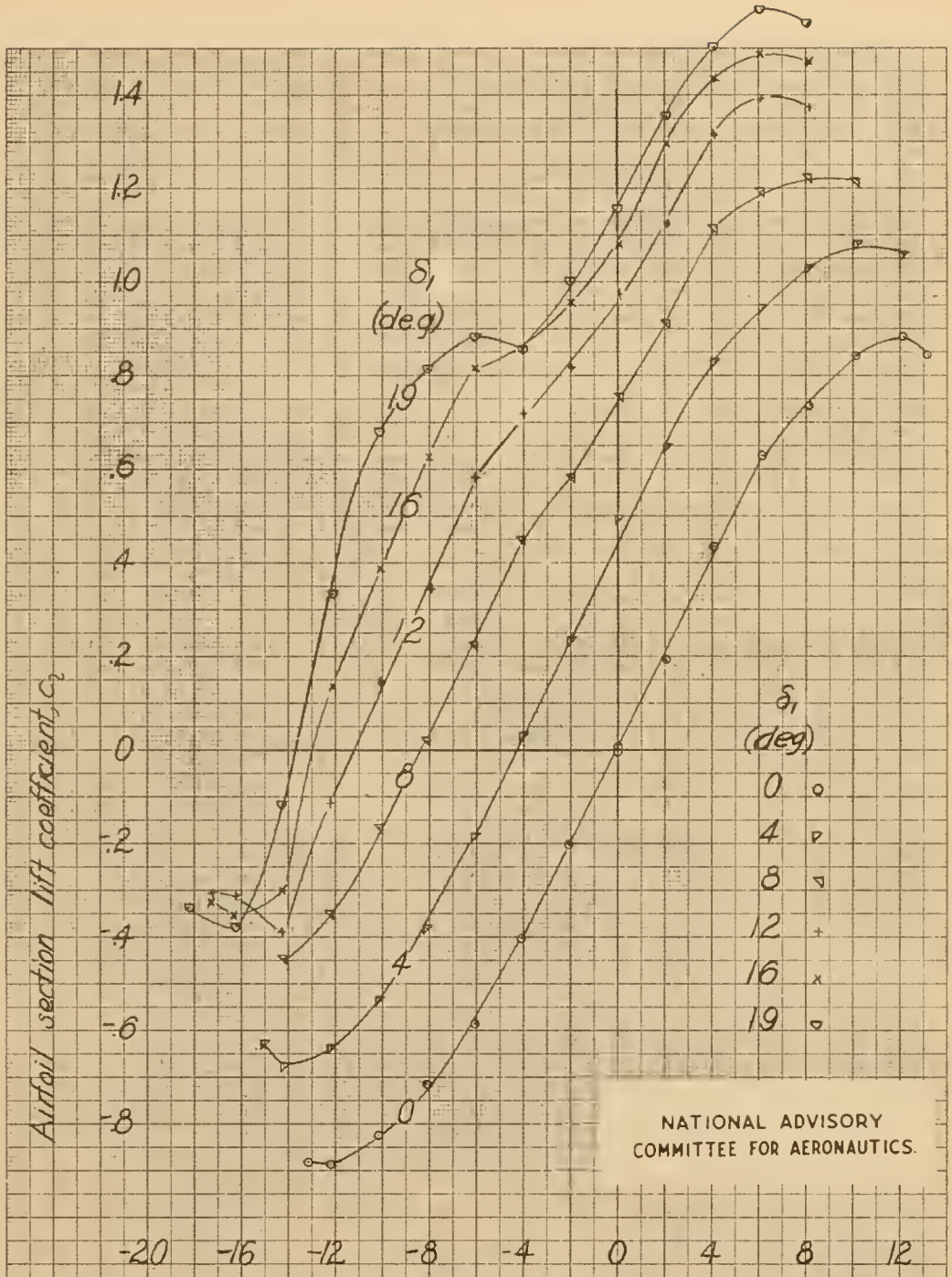

Figure 7.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.40c, internal balance $\frac{d\delta_4}{d\delta_1} = 1$.

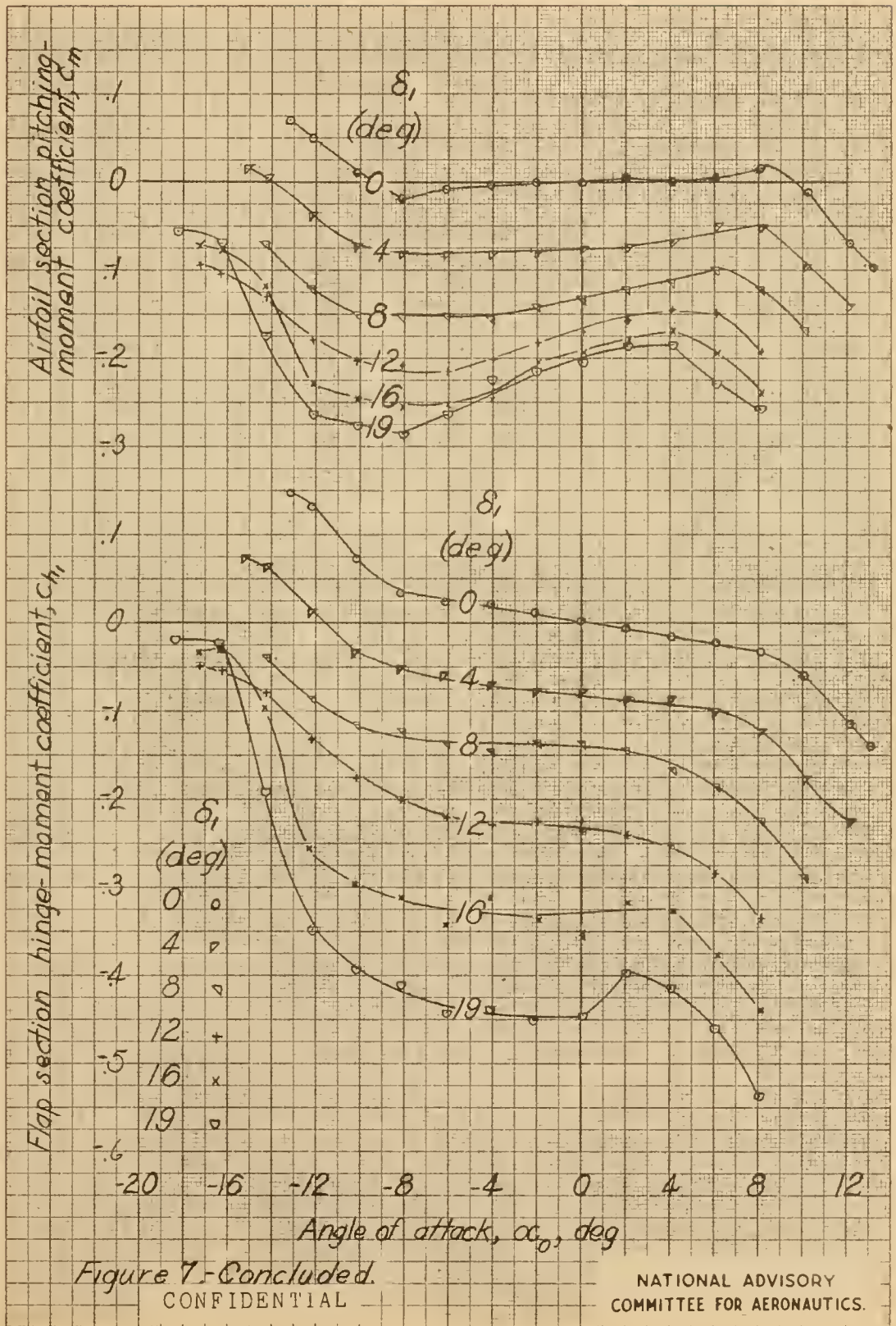

Figure 7.- Concluded.

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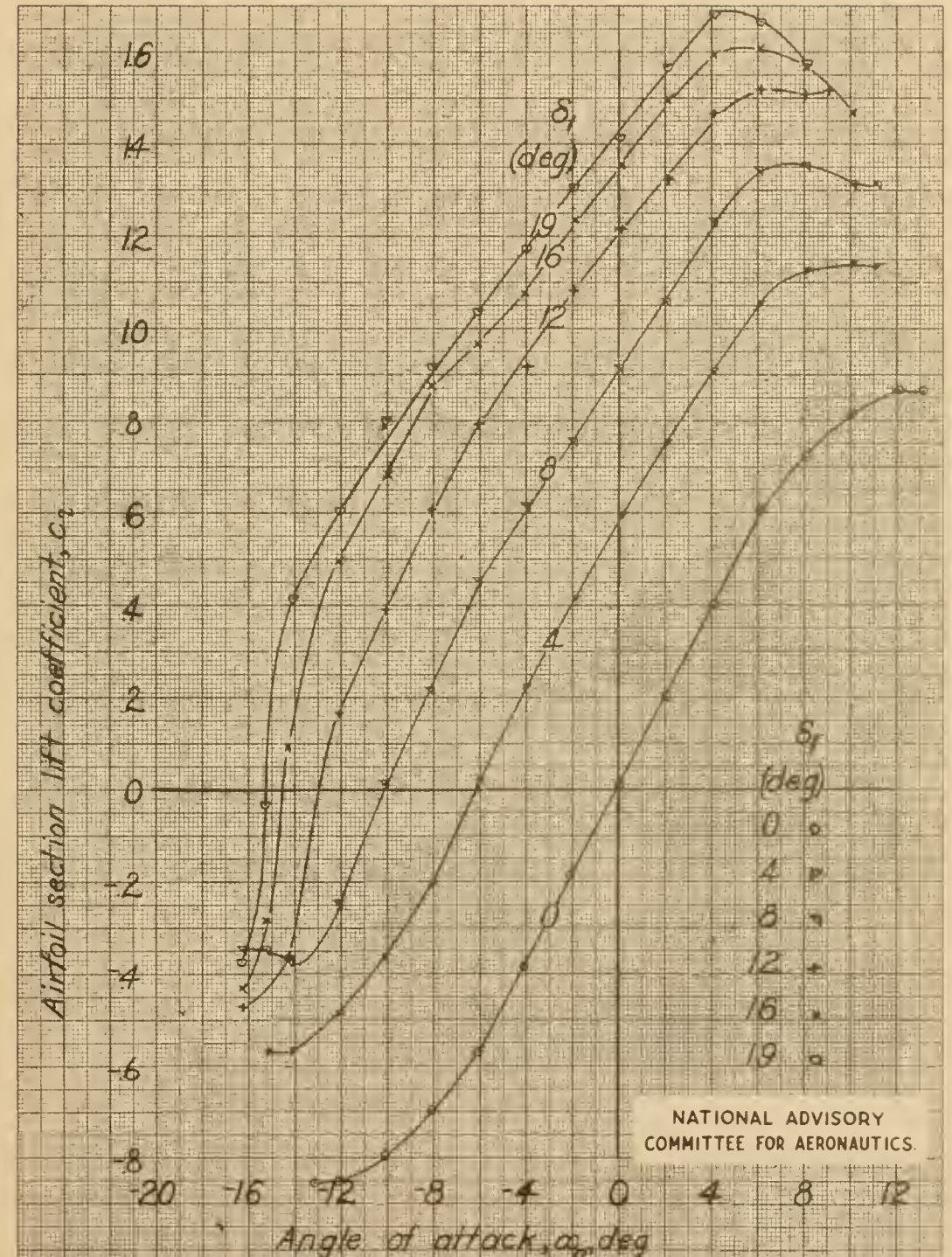

Figure 8.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30 c double flap with a 0.40 c, internal balance. $\frac{d\delta_2}{d\delta_1} = 2$.

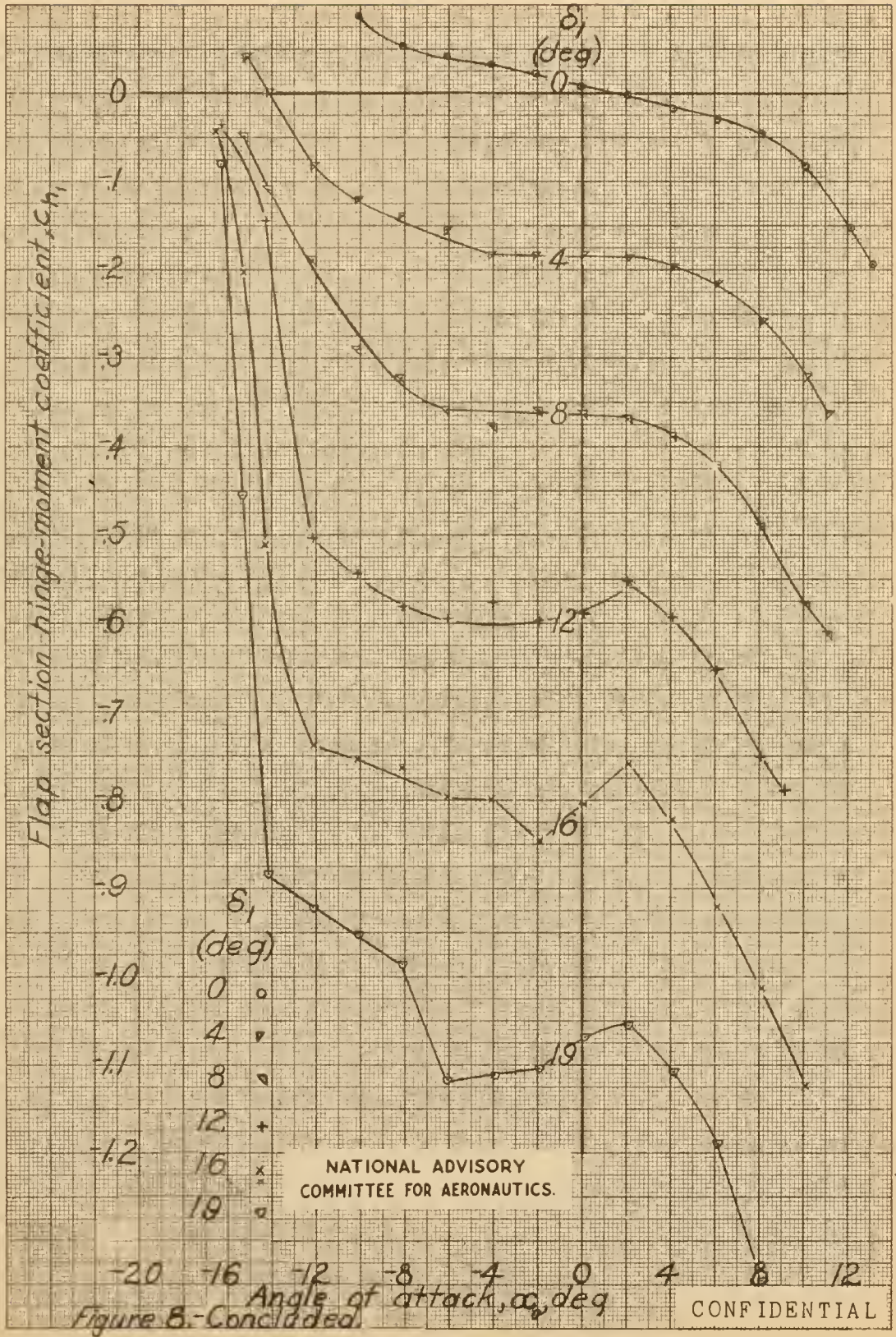

Figure 8.- Concluded.

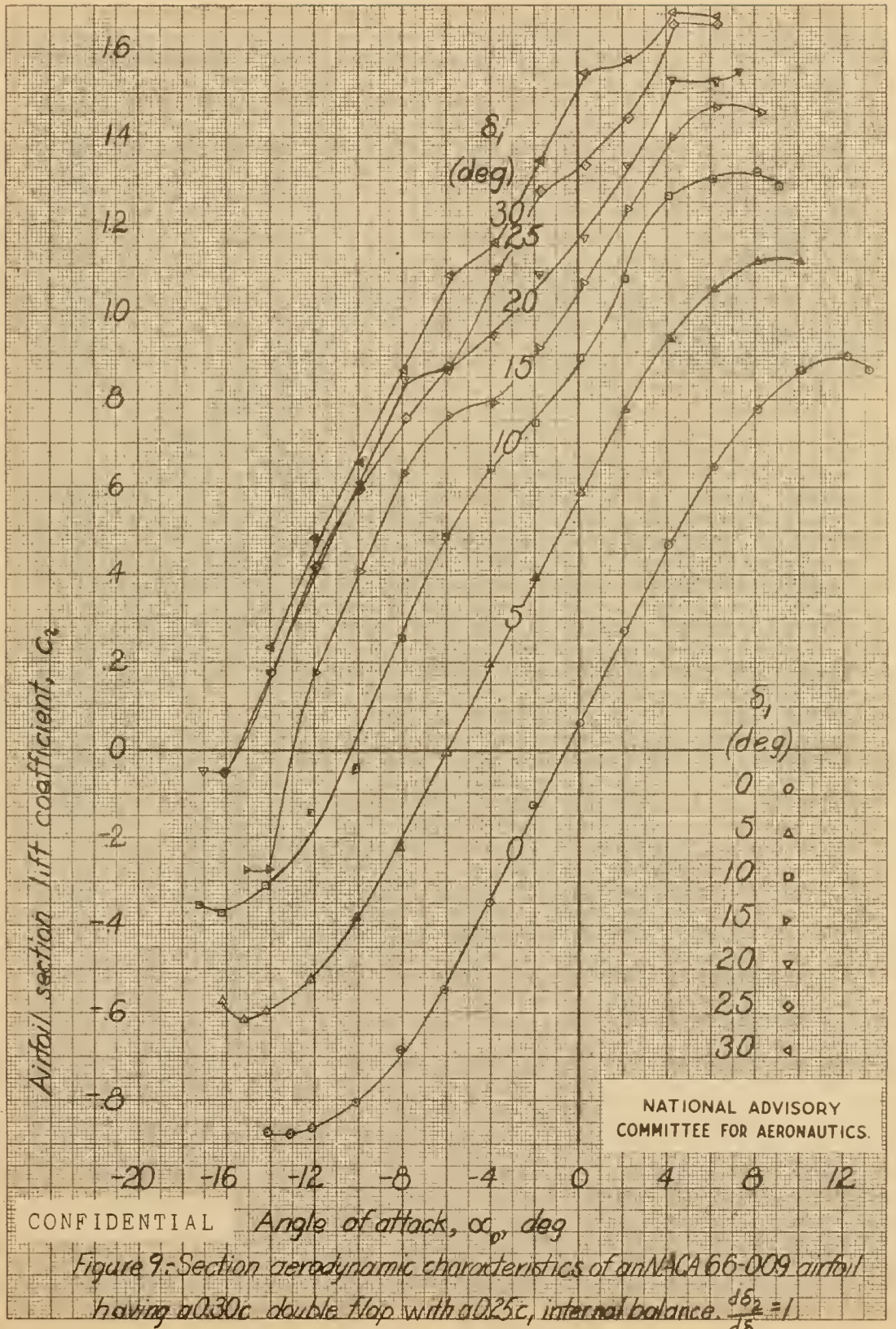

Figure 9.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.25c, internal balance. $\frac{d\delta_2}{d\delta_1} = 1$

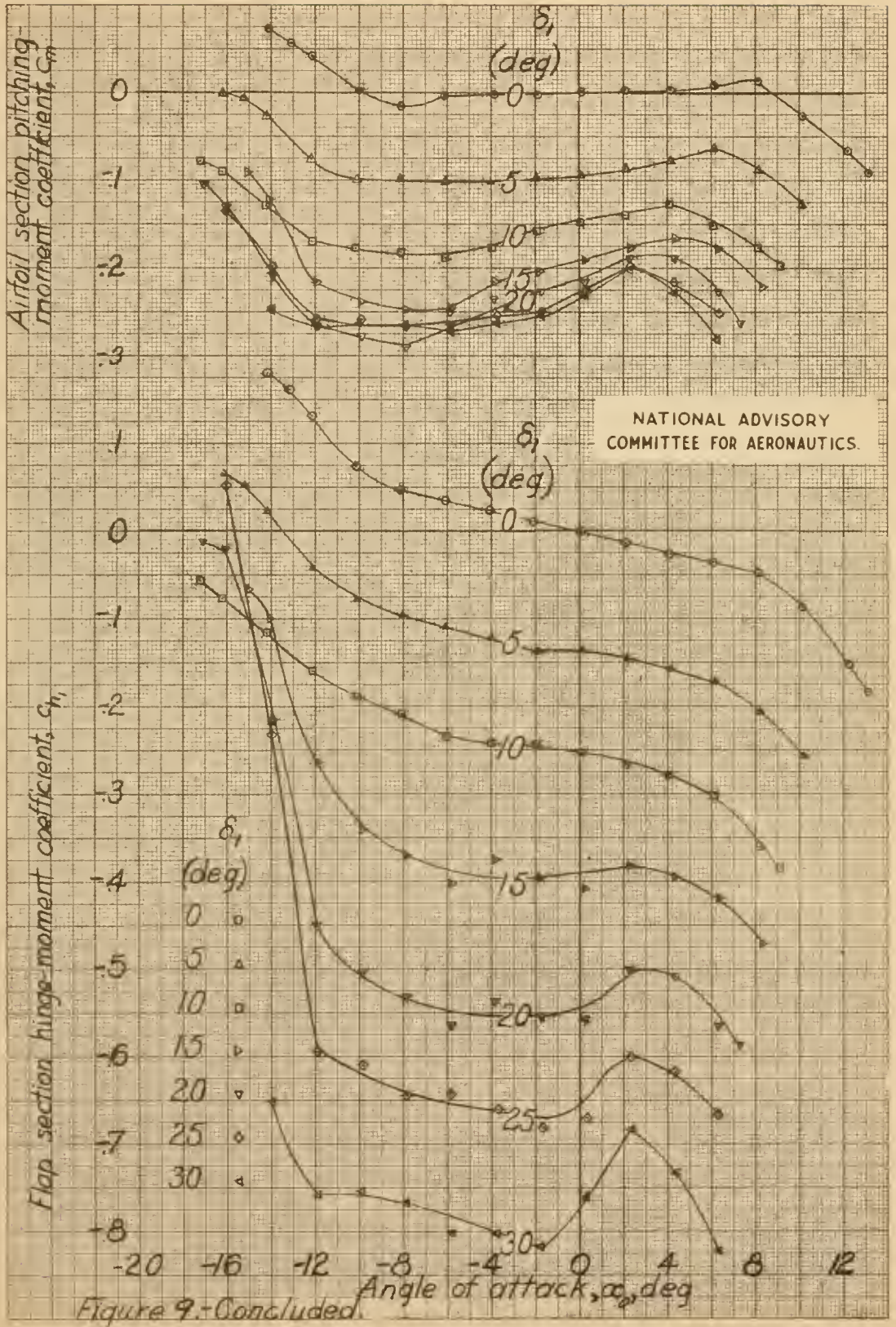

Figure 9.- Concluded.

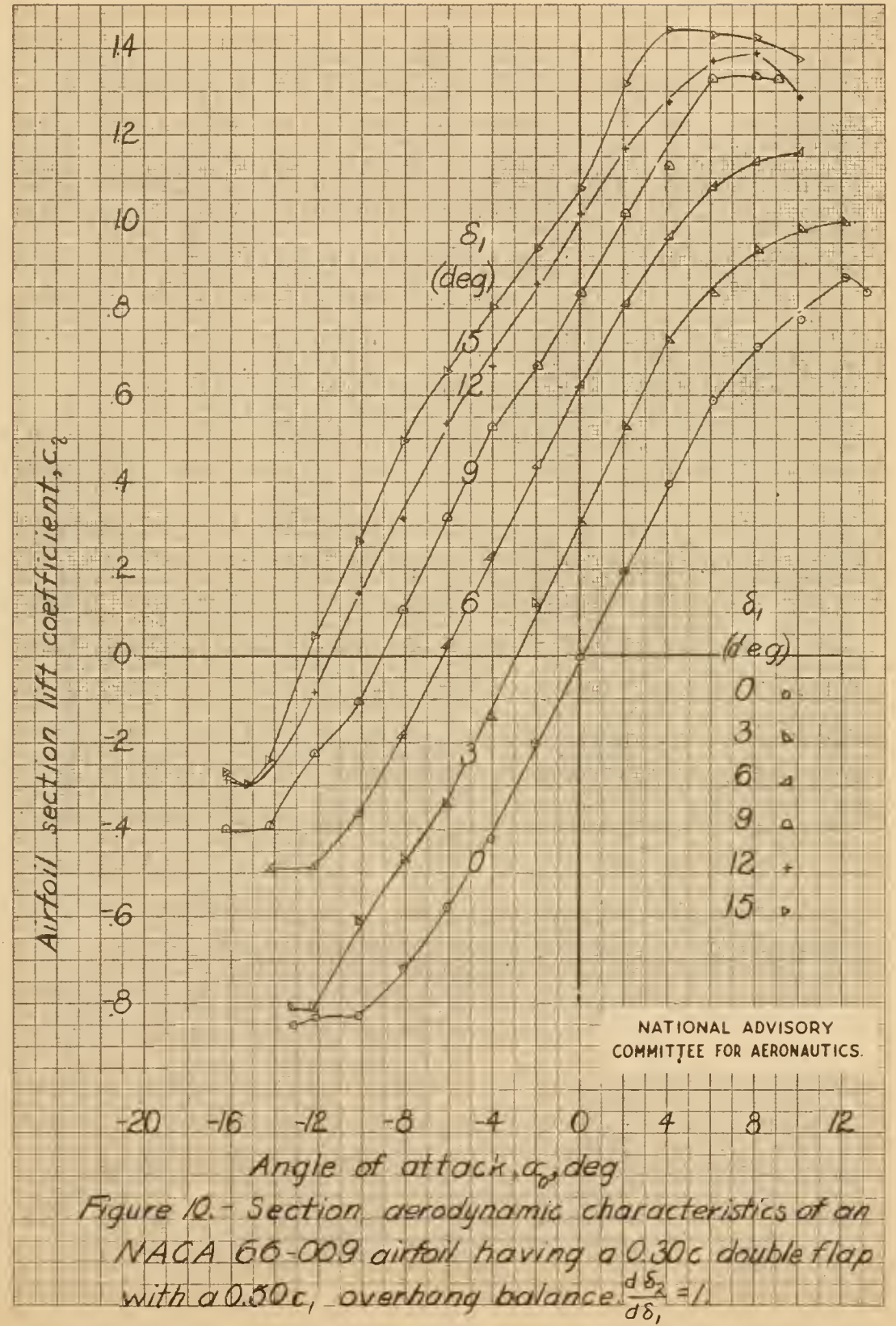

Figure 10.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.50c, overhang balance. $\frac{d\delta_2}{d\delta_1} = 1$.

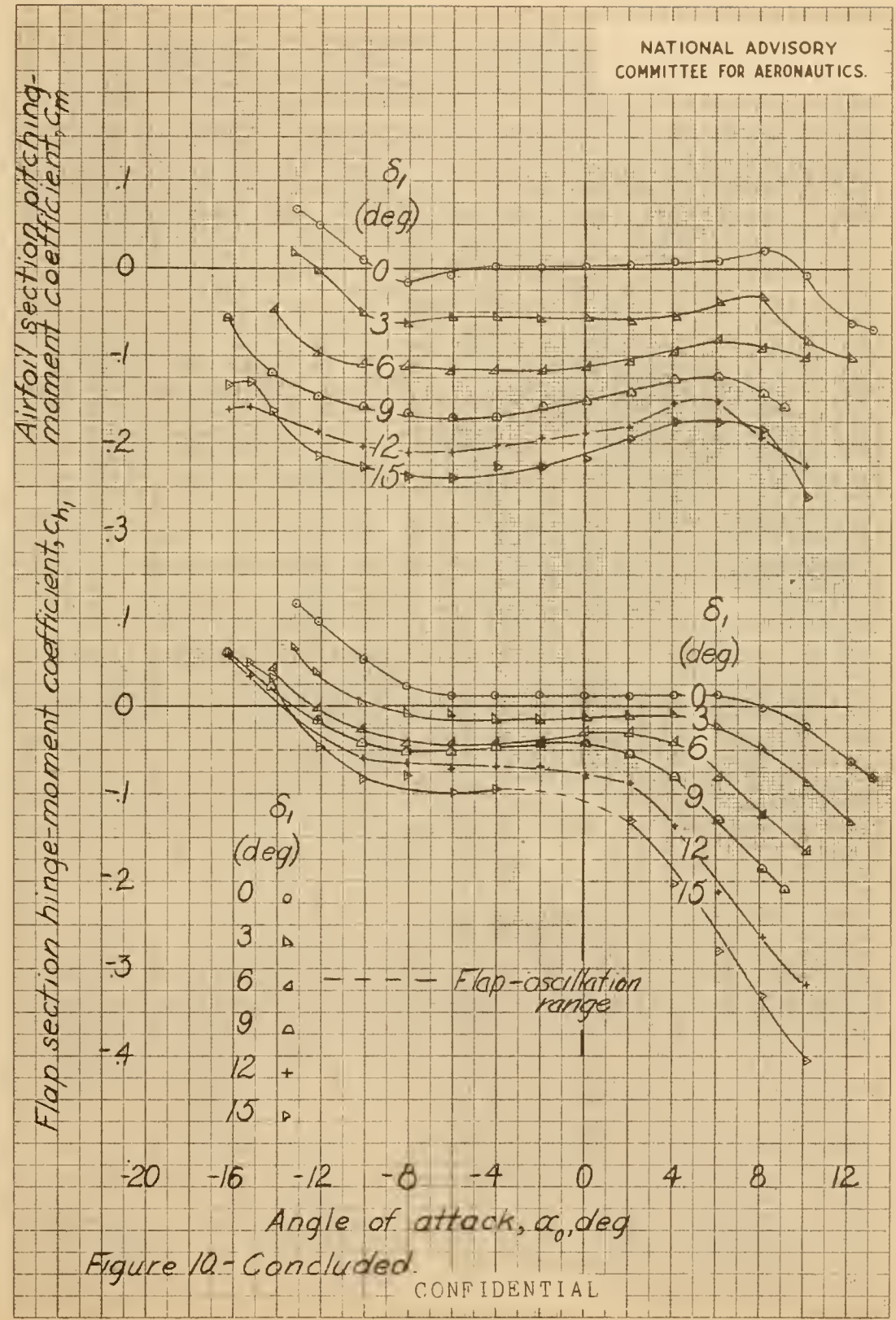

Figure 10.- Concluded.

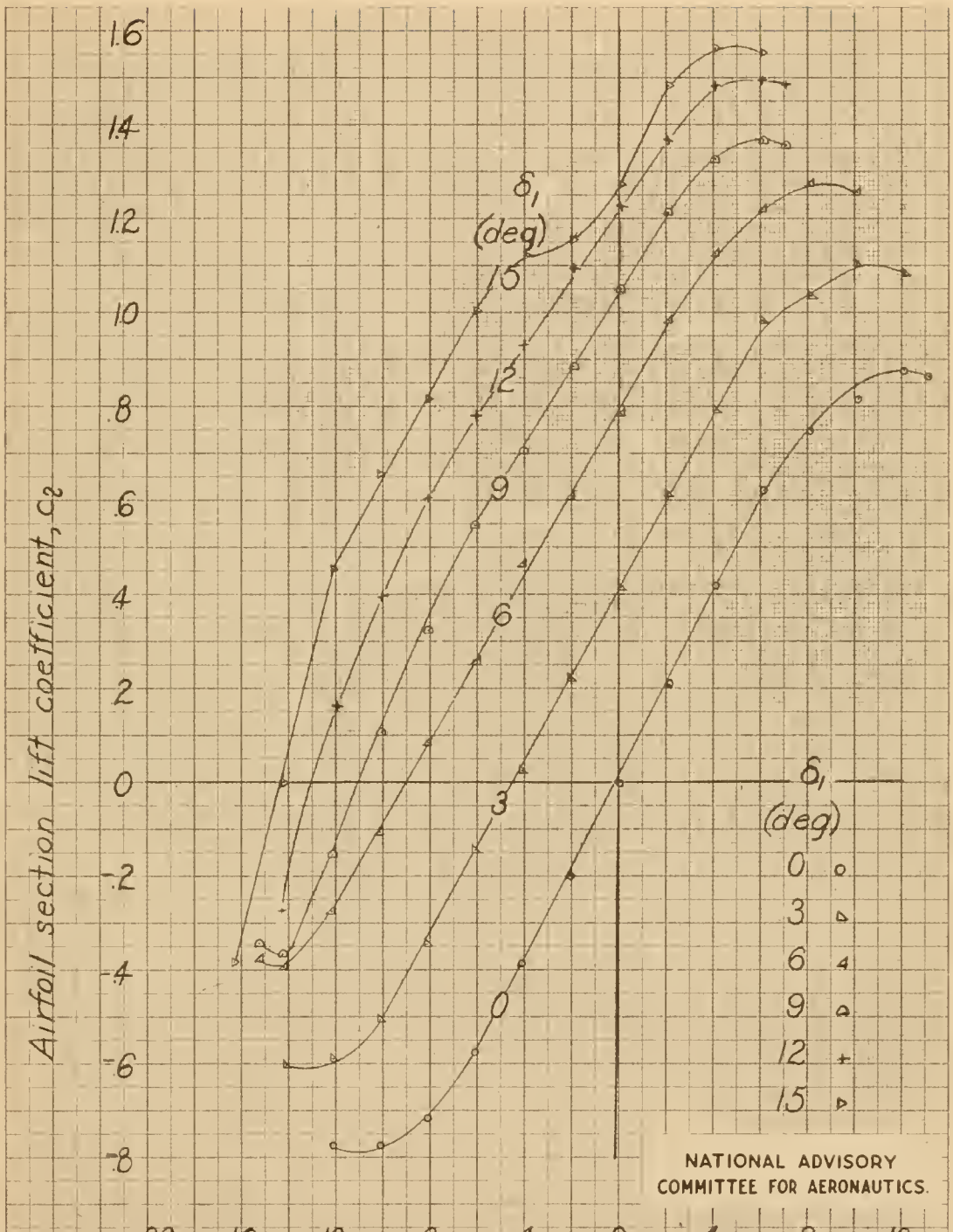

Figure 11.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.50c, overhang balance. $\frac{d\delta_2}{d\delta_1} = 2$.

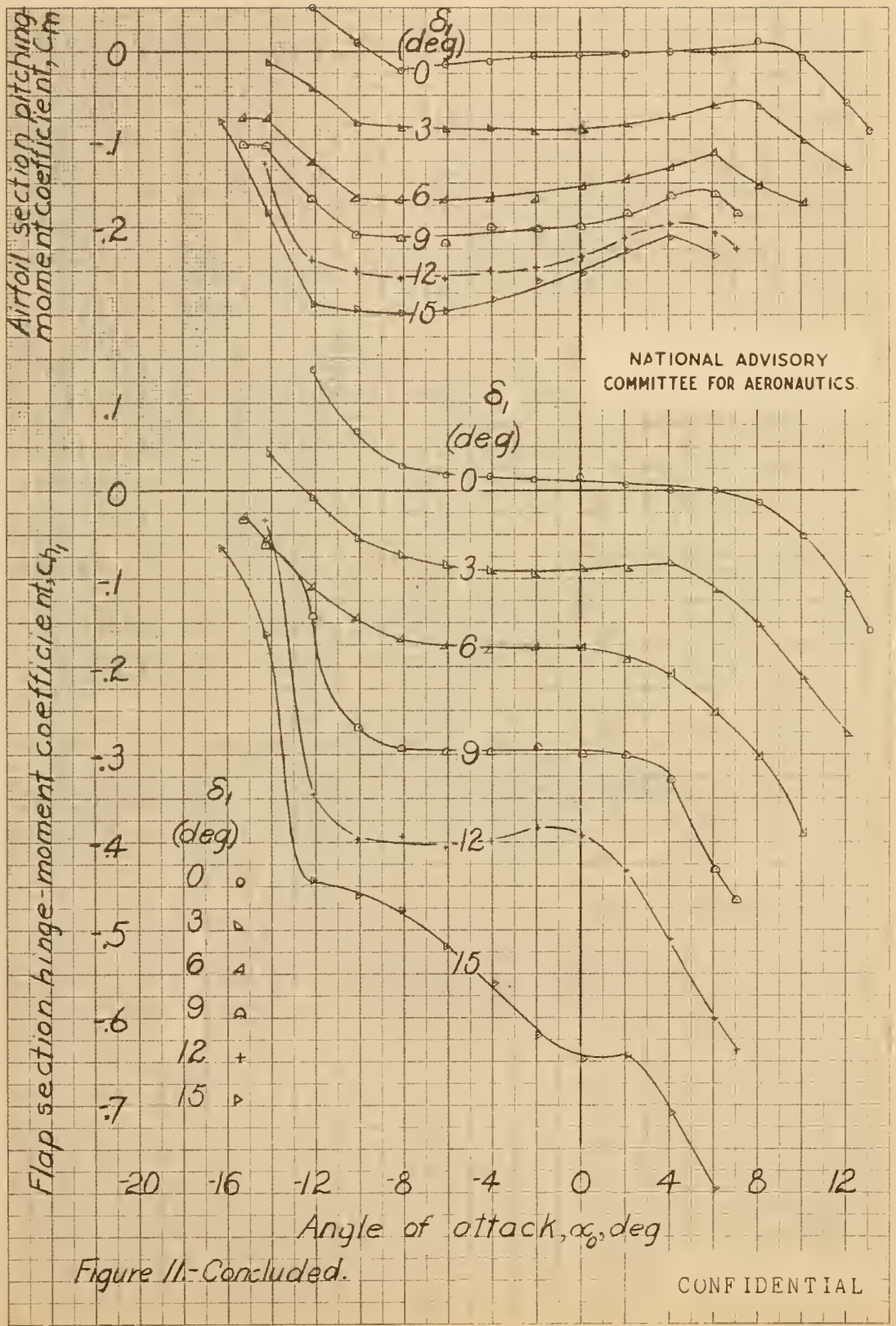

Figure 11.- Concluded.

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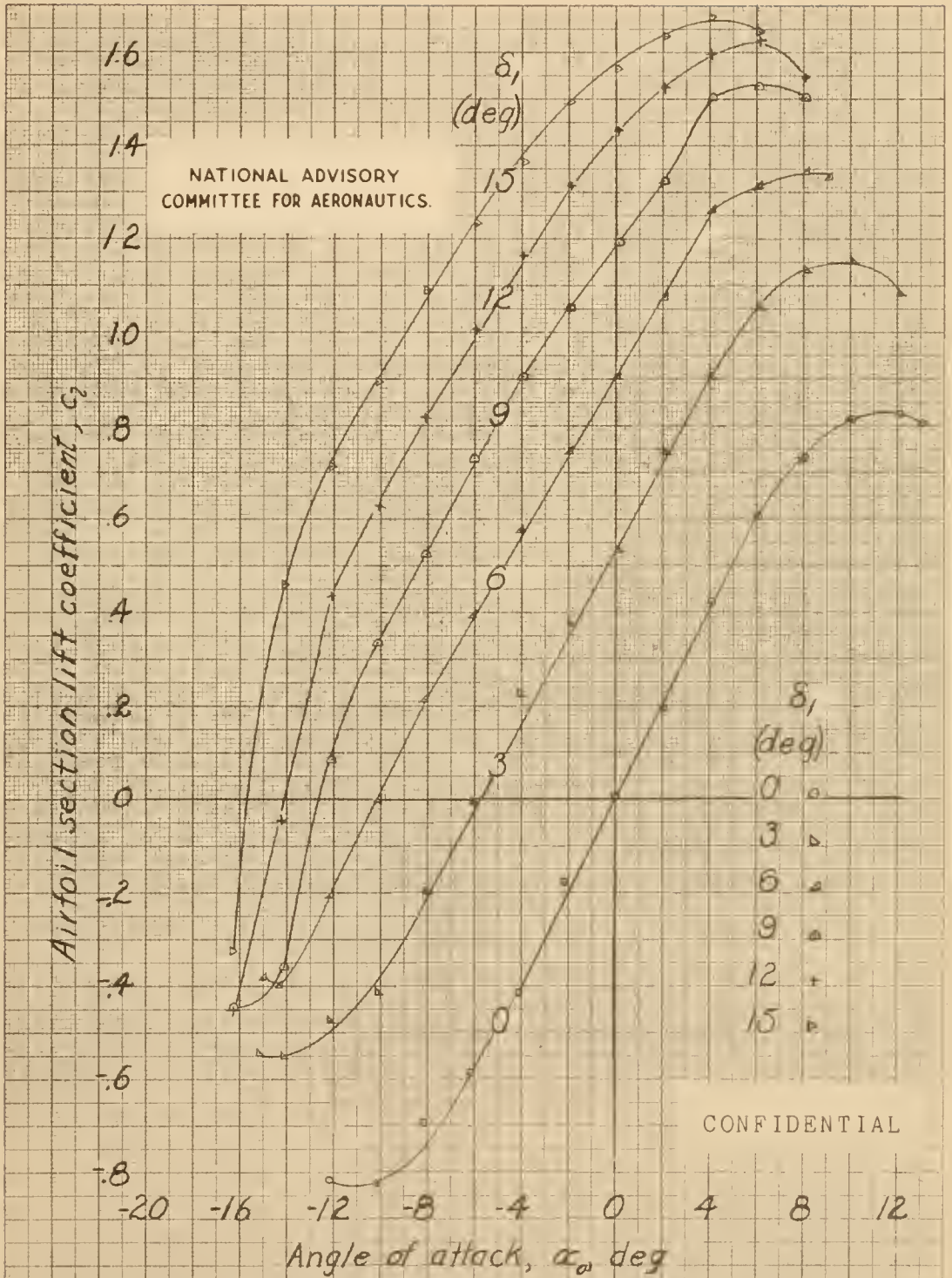

Figure 12.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.50c, overhang balance. $\frac{d\delta_2}{d\delta_1} = 3$

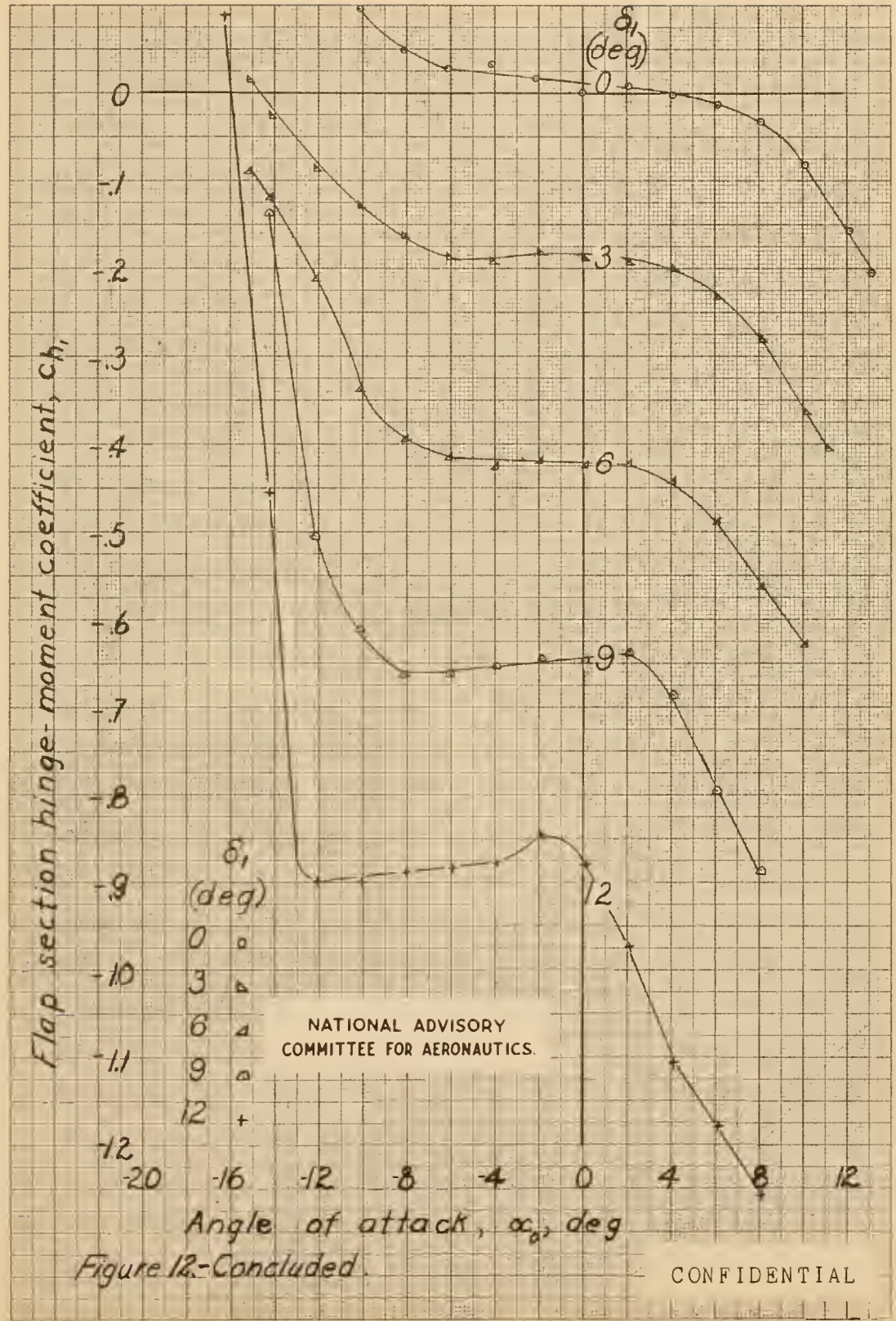

Figure 12.- Concluded.

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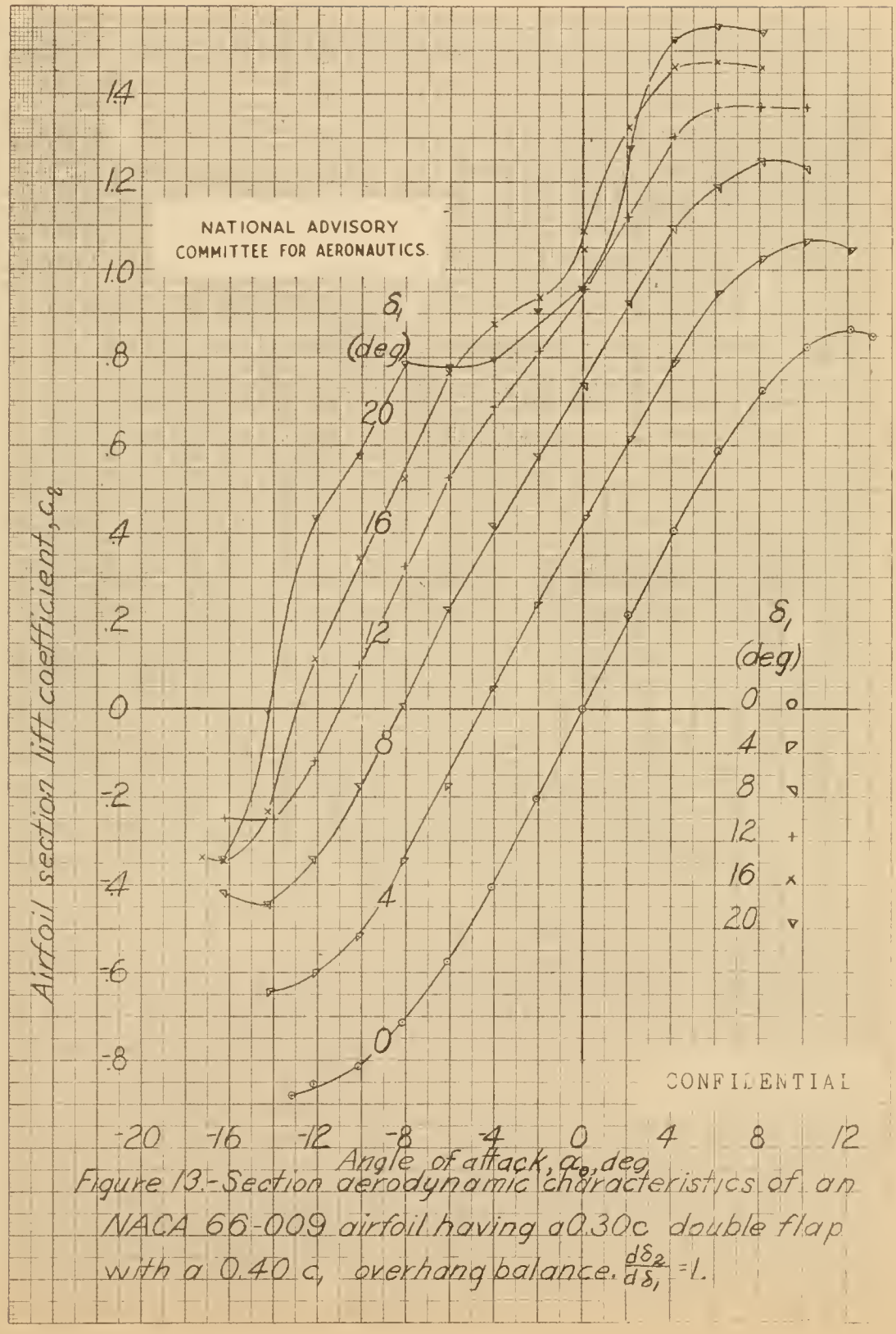


Figure 13.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.40 c, overhang balance. $\frac{d\delta_2}{d\delta_1} = 1$.

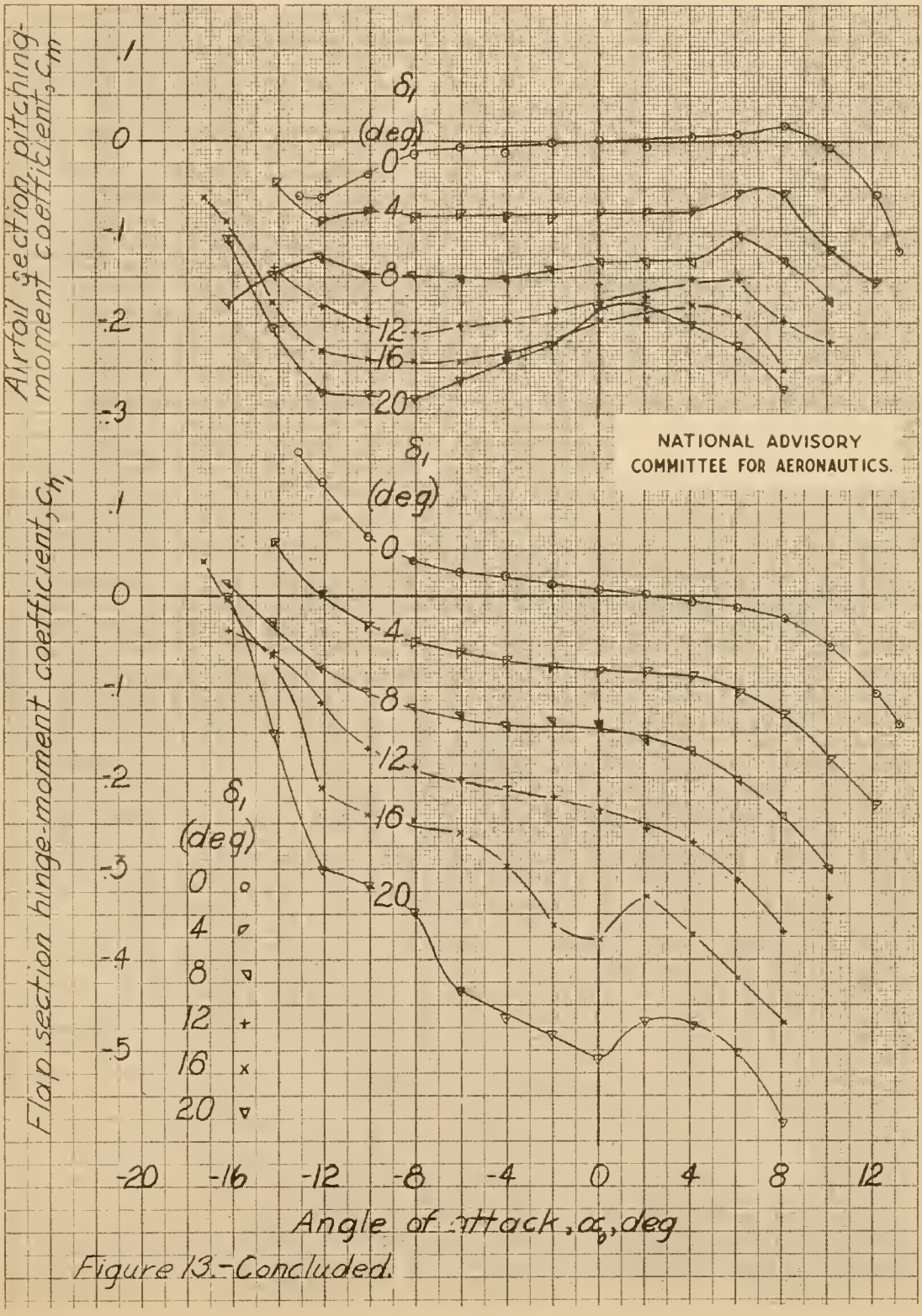


Figure 13.- Concluded.

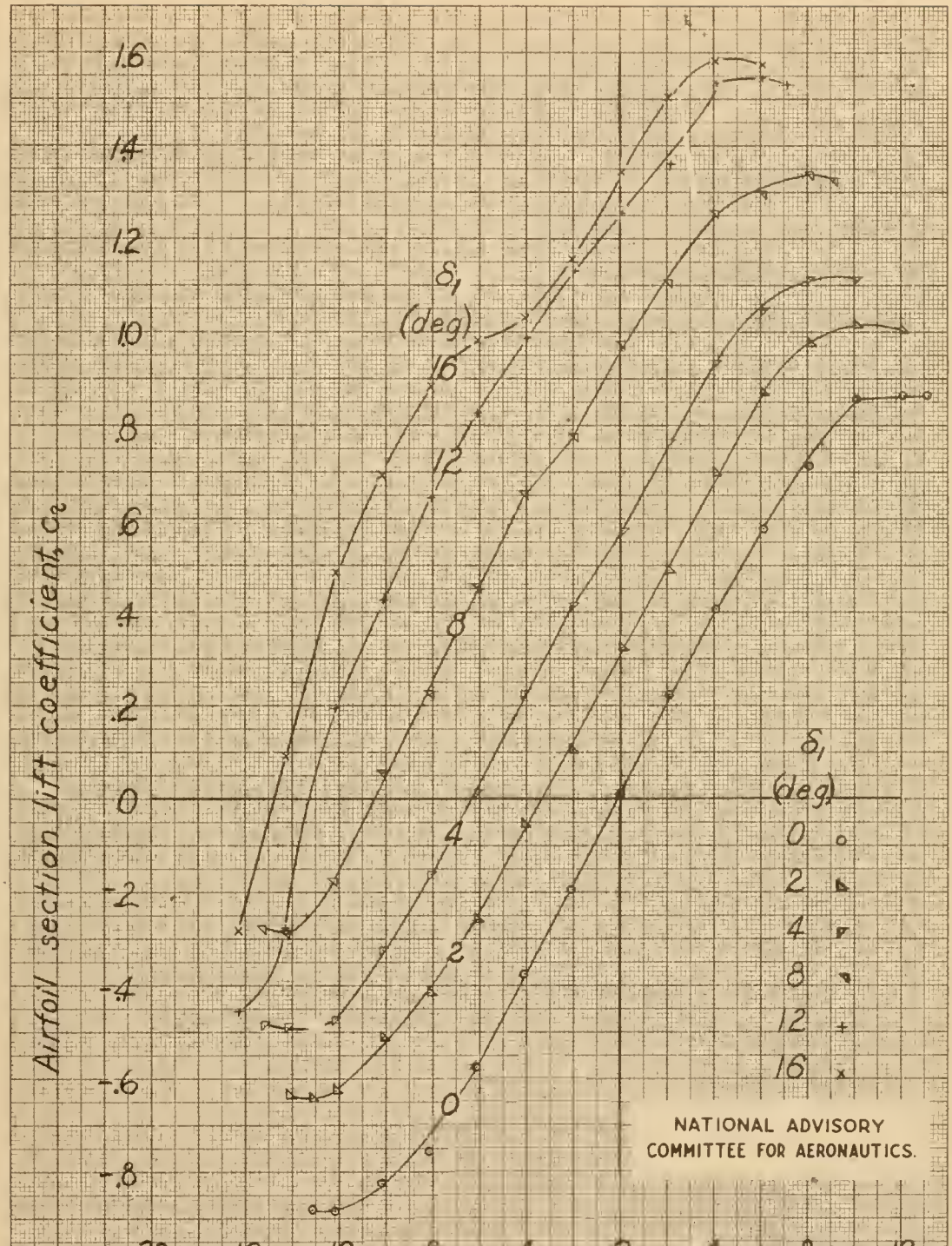
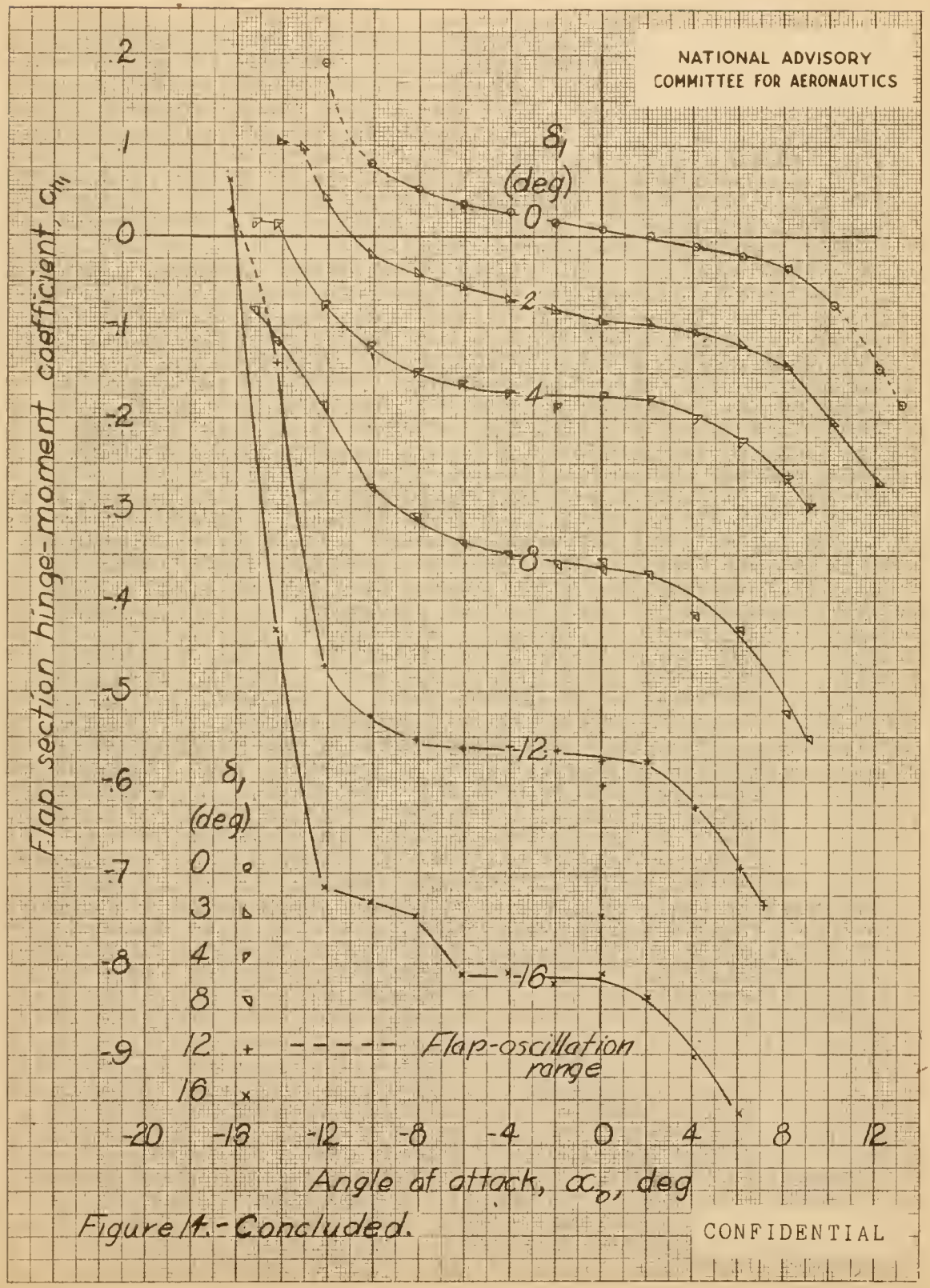


Figure 14.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.40c_1 overhang balance. $\frac{d\delta_2}{d\delta_1} = 2$.



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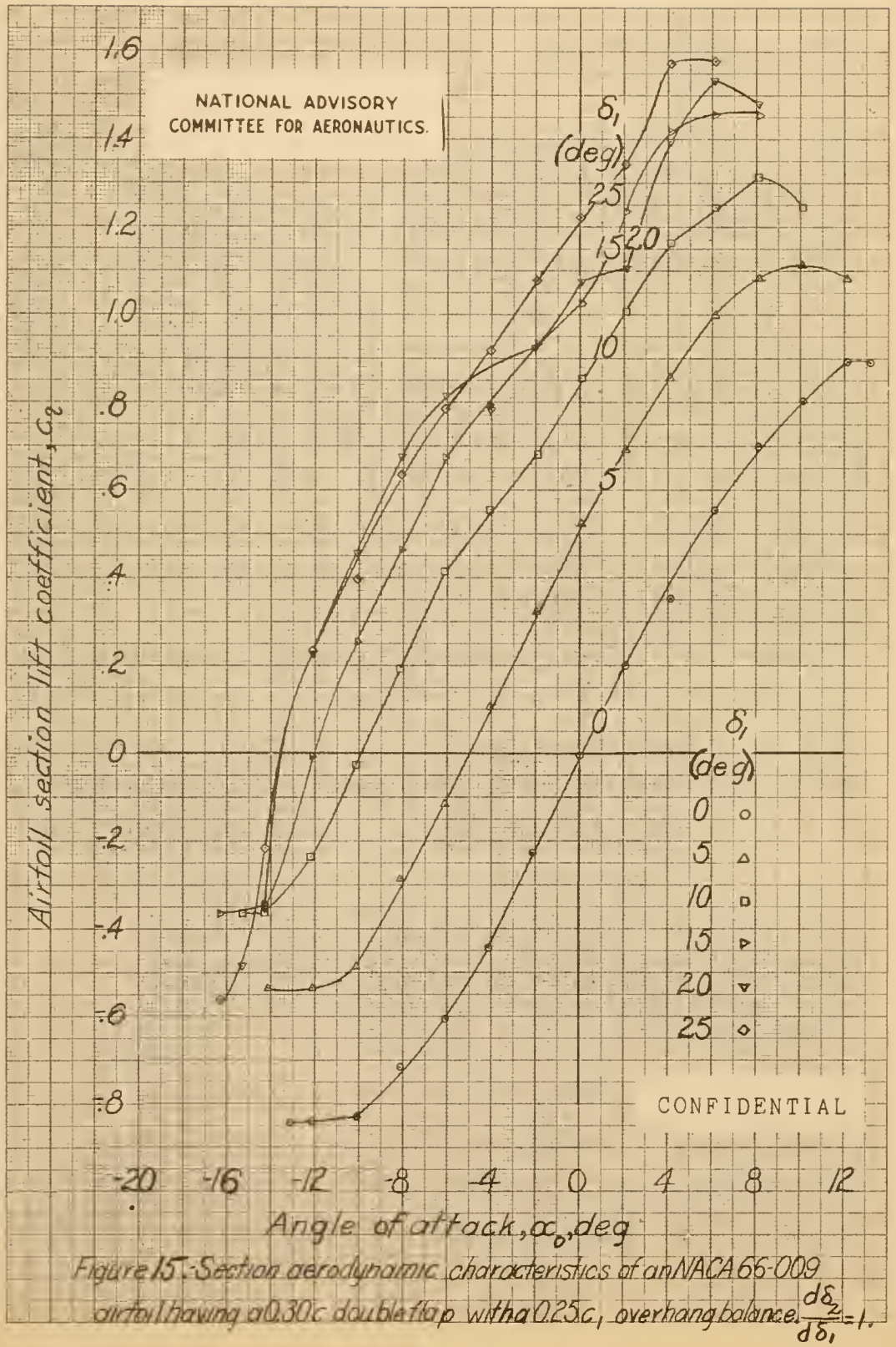


Figure 15.- Section aerodynamic characteristics of an NACA 66-009 airfoil having a 0.30c double flap with a 0.25c, overhang balance. $\frac{d\delta_2}{d\delta_1} = 1.$

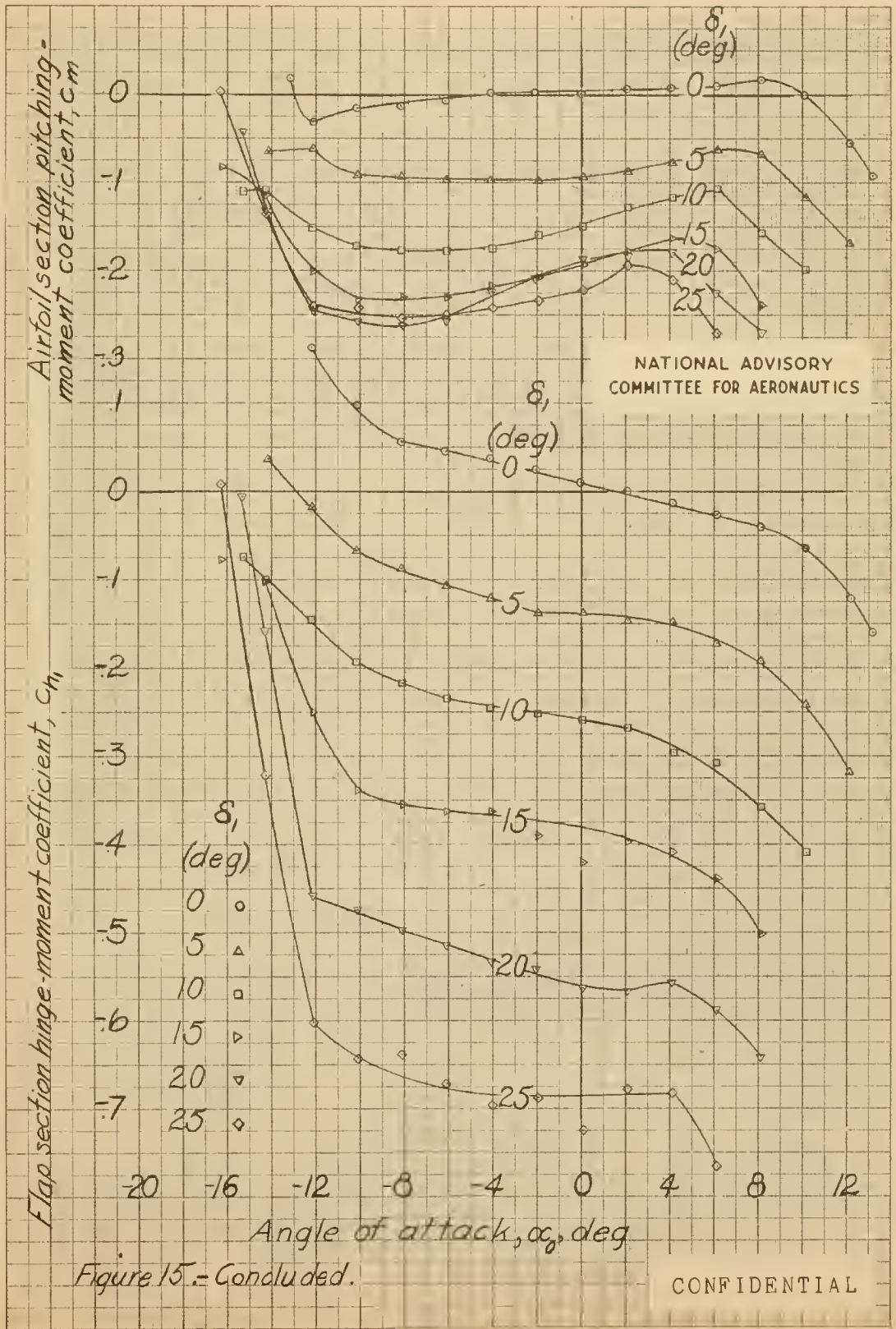


Figure 15.- Concluded.

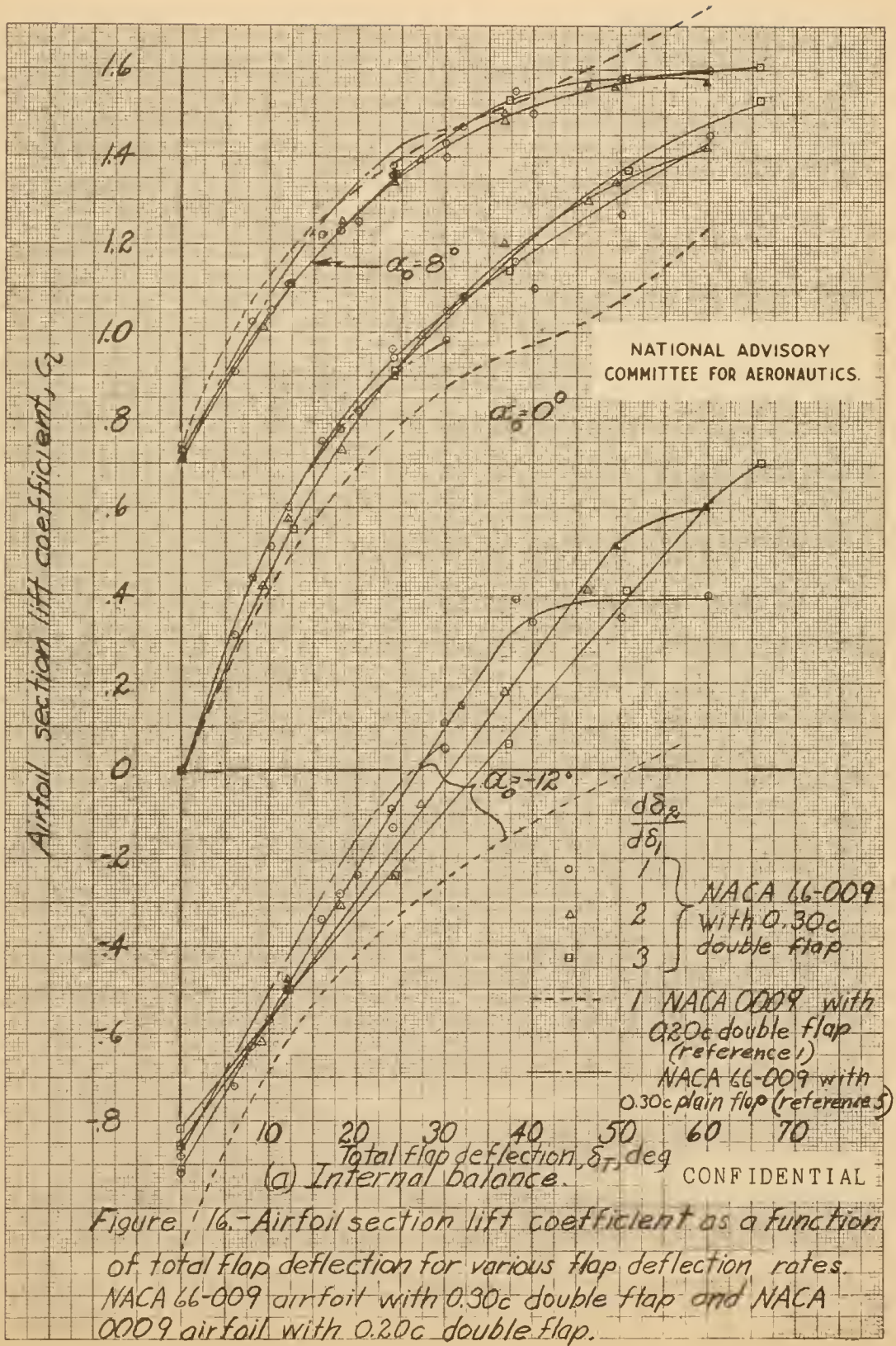
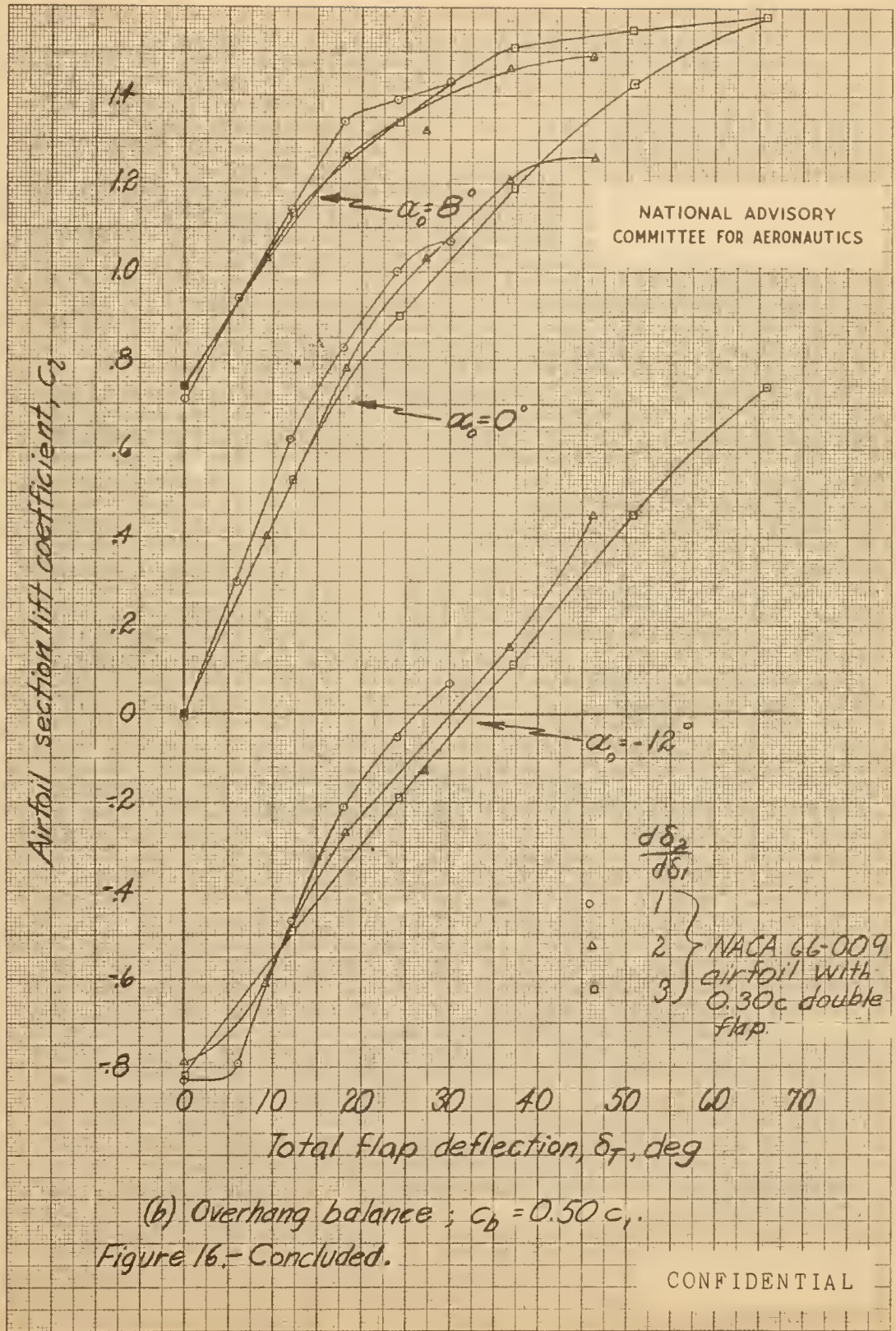
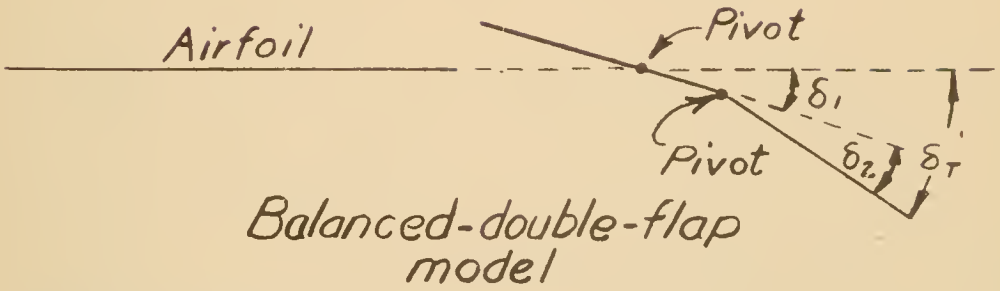


Figure 16.- Airfoil section lift coefficient as a function of total flap deflection for various flap deflection rates. NACA 66-009 airfoil with 0.30c double flap and NACA 0009 airfoil with 0.20c double flap.



(b) Overhang balance; $c_b = 0.50\,c_1$.

Figure 16.- Concluded.



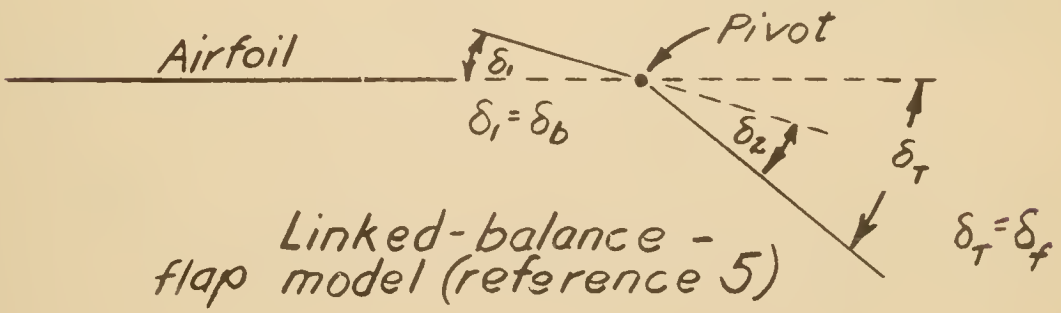


Figure 17.- Schematic line drawing of balanced-double-flap model and linked-balance model.

$$\delta_1 + \delta_2 = \delta_T \; ; \; \frac{d\delta_1}{d\delta_T} = \frac{1}{1 + \frac{d\delta_2}{d\delta_1}}$$

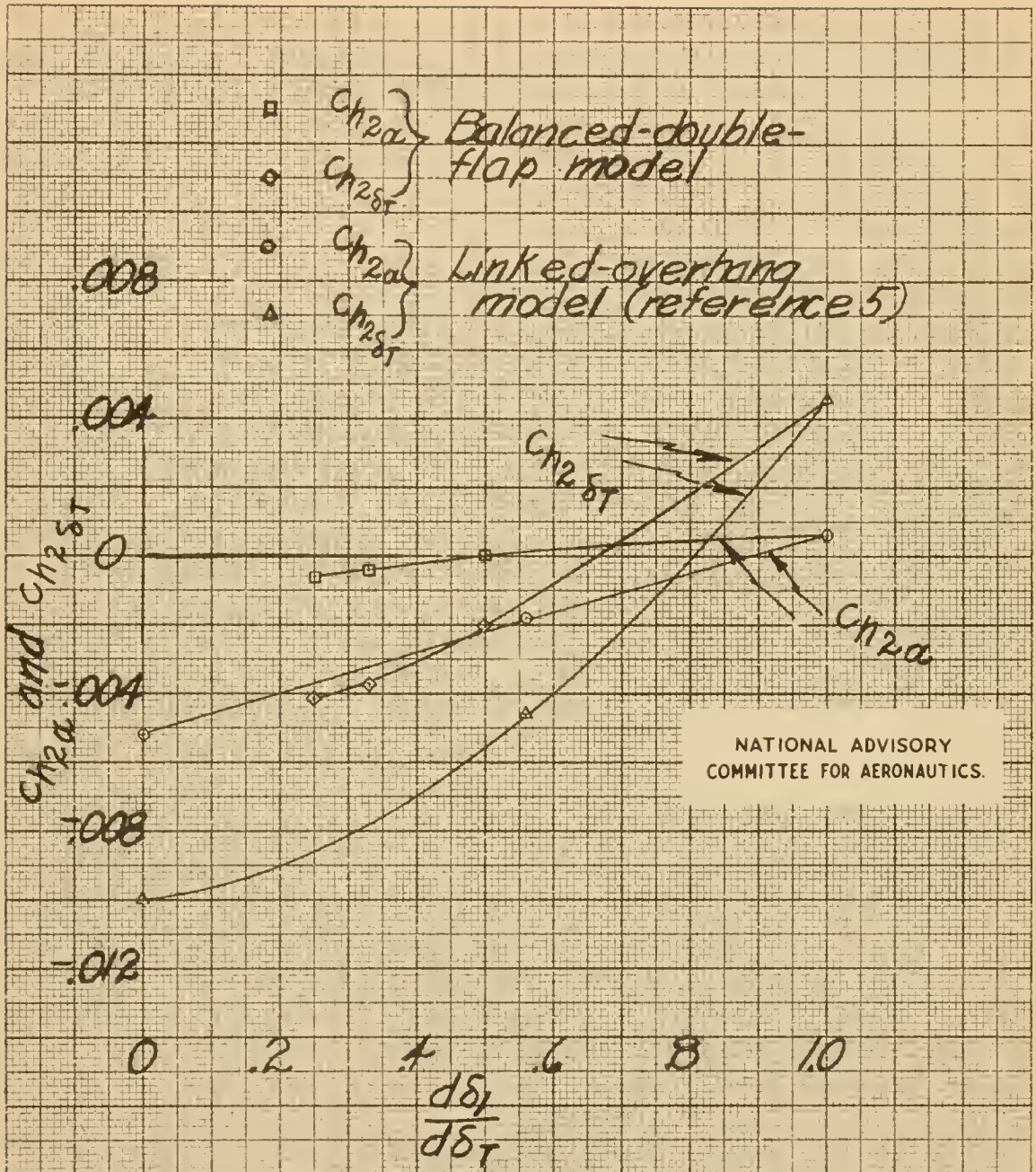
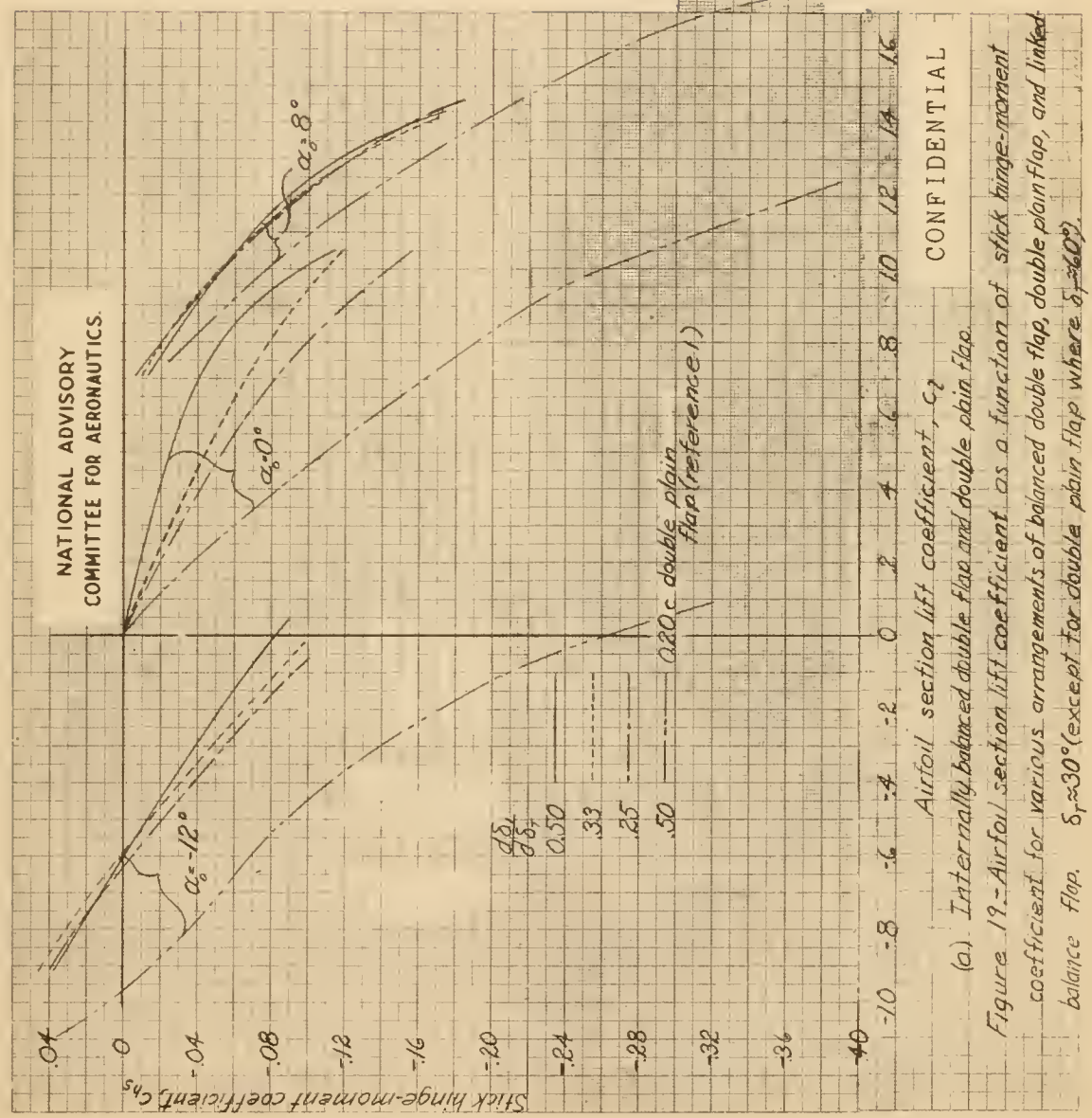


Figure 18.- Variation of parameters $C_{h_{2\alpha}}$ and $C_{h_{2\delta_T}}$ with rate of deflection for the balanced-double-flap model and the linked-overhang model. $c_b = 0.50c_f$.



(a). Internally balanced double flap and double plain flap.

Figure 19.- Airfoil section lift coefficient as a function of stick hinge-moment coefficient for various arrangements of balanced double flap, double plain flap, and linked balance flap. $\delta_f = 30°$ (except for double plain flap where $\delta_f = 60°$).

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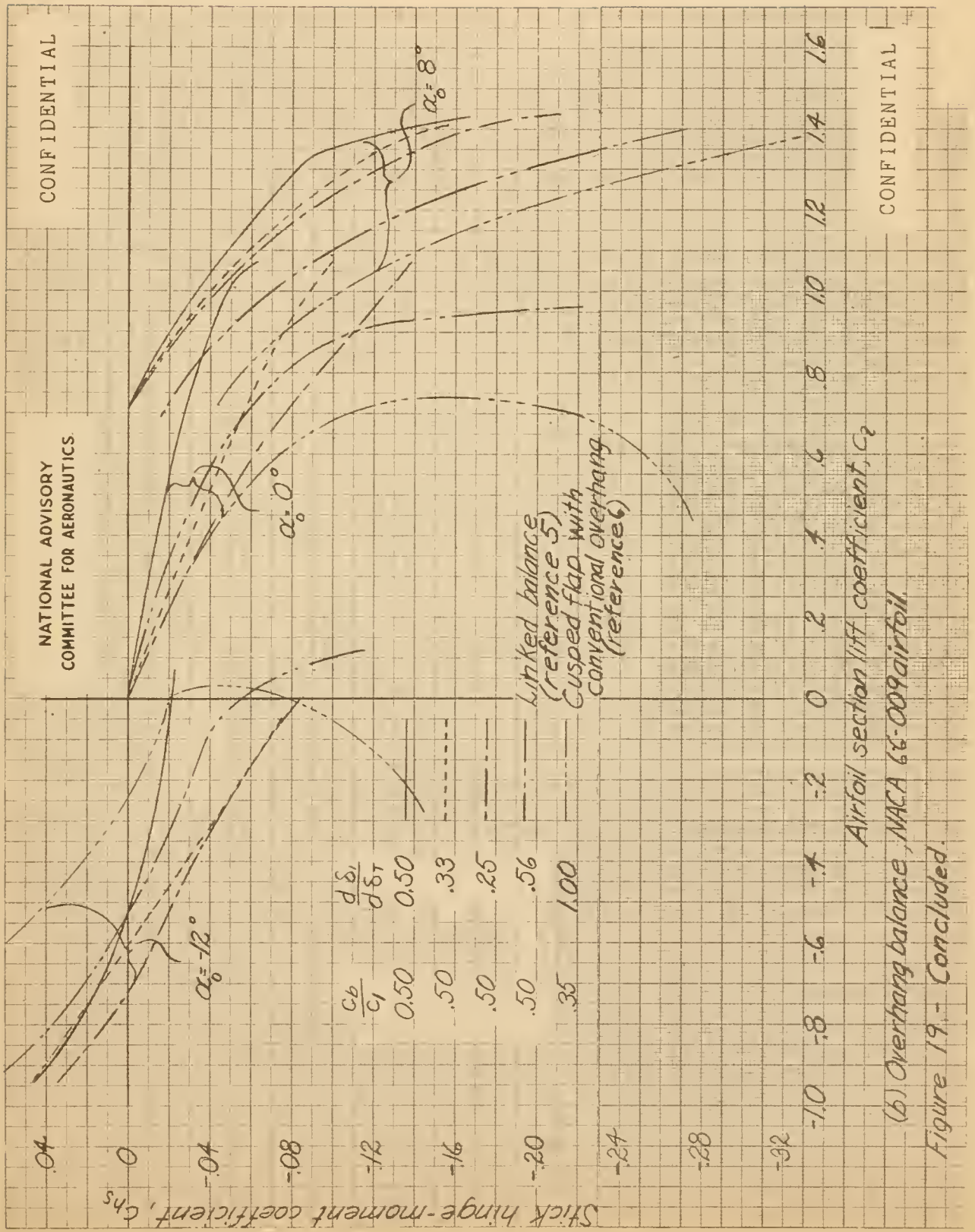

(b) Overhang balance, NACA 66-009 airfoil.

Figure 19.- Concluded.

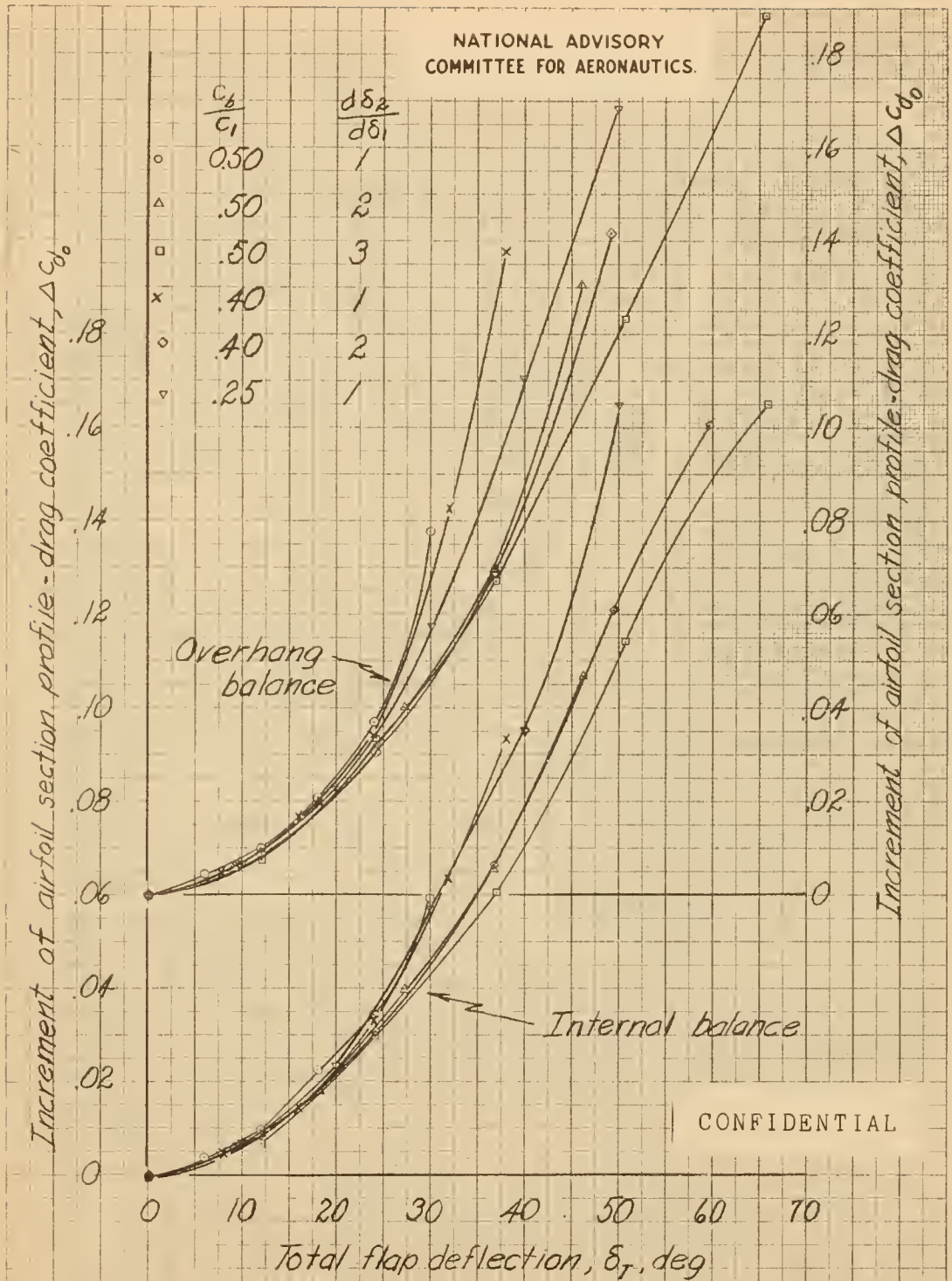

Figure 20.- Increment of airfoil section profile-drag coefficient caused by flap deflection. NACA 66-009 airfoil having a 0.30c double flap.

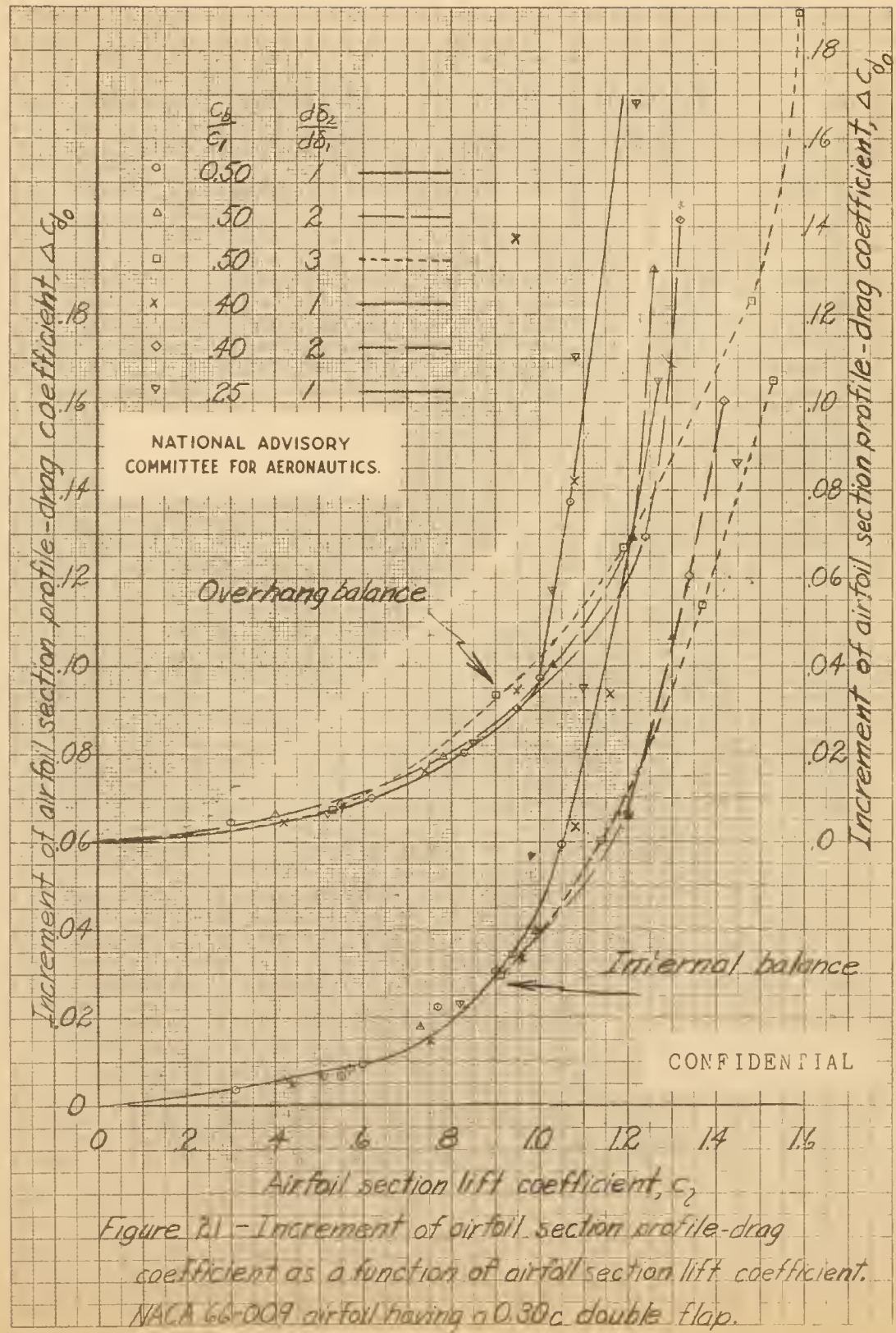

Figure 21 - Increment of airfoil section profile-drag coefficient as a function of airfoil section lift coefficient. NACA 66-009 airfoil having a 0.30c double flap.

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